Stanford University Electrical Engineering
Space, Telecommunications, and
Radioscience (STAR) Laboratories

A tmospheric
W eather
E ducational
S ystem for
O bservation and
M odeling of
E lectromagnetic effects

Documentation

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i. Introduction to the Stanford University 2005 VLF Receiver

The Stanford University Electrical Engineering Department's Very Low Frequency (VLF) group is engaged in studies of electromagnetic phenomenon in the ionosphere and magnetosphere. One of the primary ways of studying these effects is through the use of ultra sensitive ground based VLF receiver instruments, consisting of an antenna (or two) and electronics to process the antenna's signal. The electronics is designed to capture frequencies in the ELF/VLF range, which is roughly 30 Hz-50 kHz. By studying the data recorded from the antenna, a wide range of atmospheric effects can be understood because they create disturbances in the typical magnetic field. A wide variety of phenomenon can be studied with ELF/VLF receivers, including but not limited to: lightning discharges (radio atmospherics), whistlers, lightning induced electron precipitation (LEP), cosmic gamma-ray flares, terrestrial gamma-ray flashes (TGFs), sprites and other optical discharges, one-hop and two-hop magnetospheric echo, ground-ionosphere coupling, solar flares, geomagnetic storms, and more.

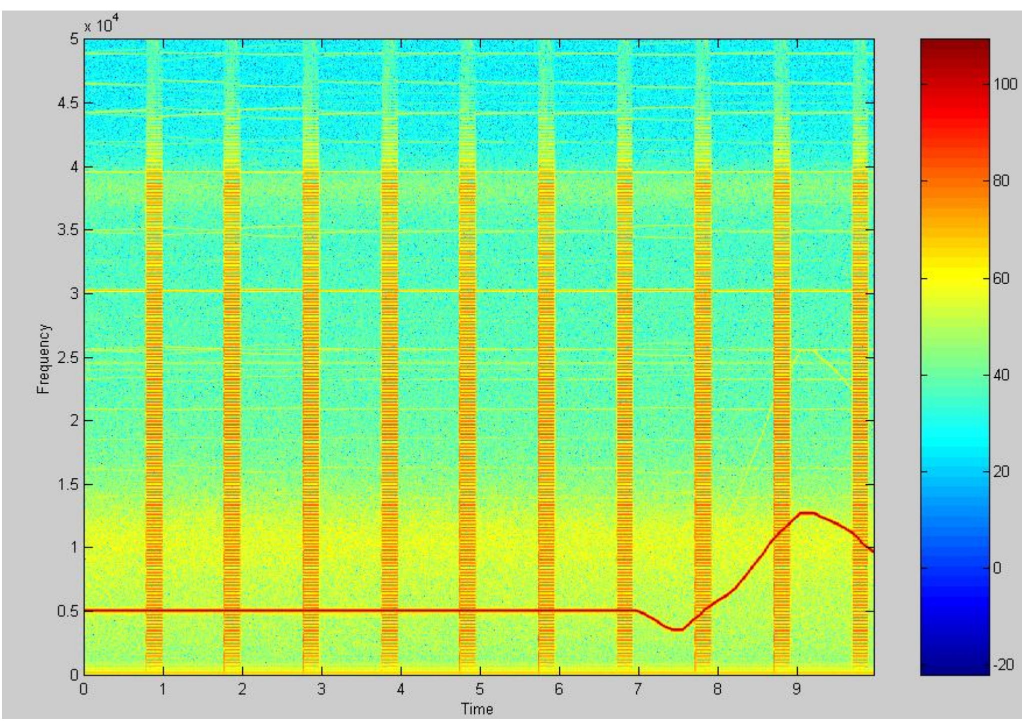
As such, the VLF group has been building and using VLF receivers for decades, refining the design over the years. The receivers have reached the point of sensitivity where nearly any signal above the ambient Earth noise floor can be detected. For example, it will pick up the miniscule signal from a digital watch in the vicinity. This is important because some of the observed disturbances in the electromagnetic field are very small.

In spring 2003, Justin Tan and Morris Cohen began building the newest incarnation, and it was completed in fall 2004. A prototype line receiver, modeled almost exactly off of an older version, was completed in June 2003. Full development began in autumn 2004, and was assembled in spring 2004. Initial field testing and final changes were made during summer 2004. A number of deployments occurred in fall 2004, during which time the support structures were finalized, and this documentation packet was formed. At that point, the receiver was named the Atmospheric Weather Educational System for Observation and Modeling of Effects, or, the AWESOME receiver. It was named as such because it arose out of a partnership between the VLF group, headed by Umran Inan, and the Solar Physics group, led by Phil and Deborah Scherrer. Its primary purpose originally was to serve as a tool for educational outreach in schools across America, and eventually the world. From this point on, the receiver will be referred to as the AWESOME monitor. Though based on

previous designs, the newest version adds a number of new improvements and modifications over the old VLF receivers, to be highlighted later. The rest of this packet will discuss the design, use, and performance of the 2005 VLF receiver.

Note that this documentation report will focus on specific working and use of this design and implementation, including the receiver electronics, all the supporting hardware and software, information needed to build and deploy, etc. For a more technical report on the design criteria for VLF receivers, performance calculations, etc, refer to Evans Paschal's report The Design of Broad-Band VLF Receivers with Air-Core Loop Antennas. This report and its conclusions laid the groundwork for some of the most important aspects of the AWESOME monitor.

The data from the 2005 VLF receiver is often used in one of two ways: Broadband analysis and narrowband analysis. In broadband analysis, the entire frequency spectrum between the cutoffs is retained, and often presented in the form of a spectrogram. Shown here is an example of a spectrogram, created by MATLAB. It shows the frequency content over a 10 second snippet. The red areas indicate strong signals at that frequency and that time, while the yellow and blue areas indicate a weak and very weak presence at those frequencies.



In this example, there is a strong single frequency signal at 5 kHz (injected externally at the input) for the first seven seconds (indicated by the horizontal red line), that then drifts around for the last few seconds (turning the knob on the signal generator). There is also a broadband signal appearing once per second (this was a test calibration signal to be discussed later). The noise floor is a bit elevated around 10 kHz as can be seen by the yellowing there. The color scale is in decibels. This spectrogram represents one channel of data.

Narrowband analysis is done a little differently. The data stream is filtered out except for one very small frequency band (usually corresponding to a VLF transmitter frequency). Using fourier analysis and demodulation, the amplitude and phase at that frequency can be determined and recorded (this is done in software). Narrowband analysis is particularly valuable when VLF instruments are in remote areas, with limited ability to transmit data back to Stanford. The narrowband data would look something like this (amplitude shown only – data taken from http://www-star.stanford.edu/~hail/exdata.html, Stanford VLF group)

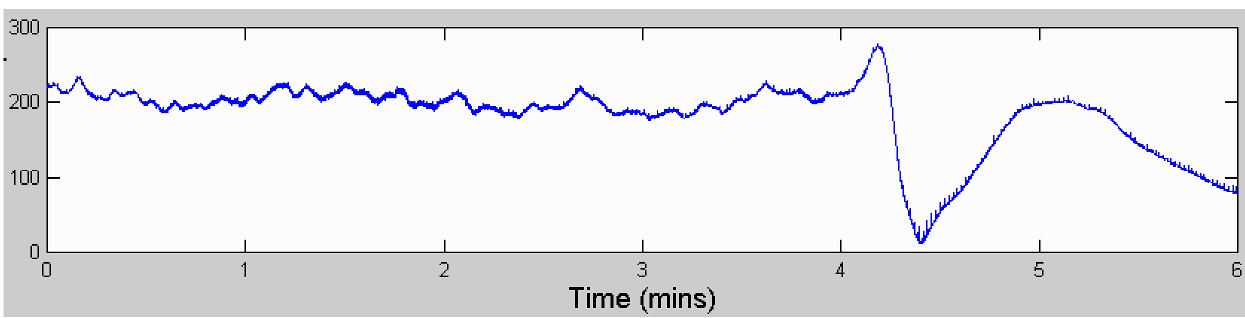


Figure 1 illustrates the basic block diagram of the VLF receiver The 2005 VLF receiver consists of three main components: First, an antenna to create electrical signals from electromagnetic field disturbances. Second is a preamplifier to amplify the signal without introducing much noise, and driving the signal over a long cable. The cable runs to a line receiver which filters and processes the data so it can be recorded. In addition, the line receiver synchronizes the data with a GPS timing signal, and passes those to a PC, with running software that records the signal and times.

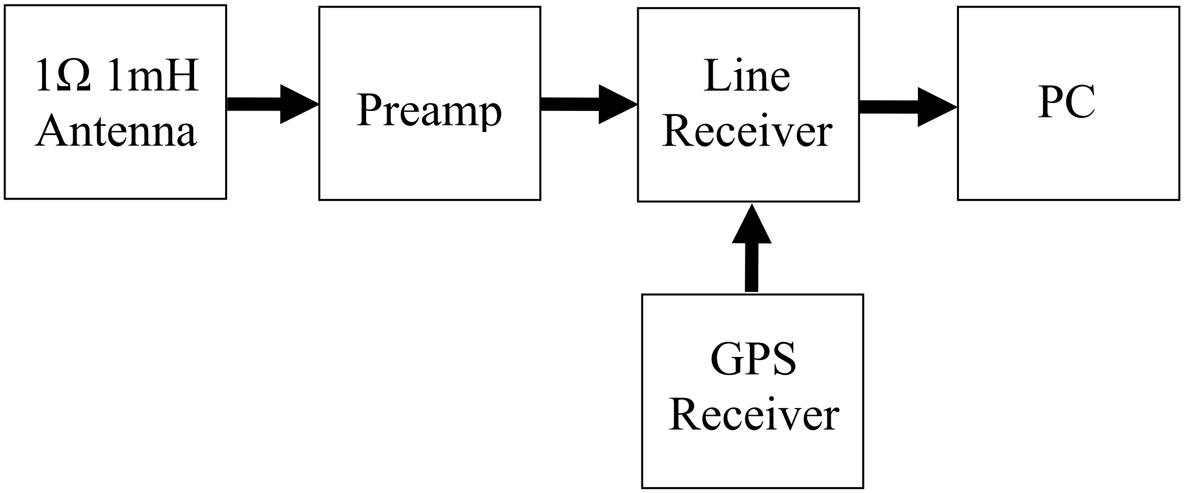


Figure 1: 2004 VLF Receiver Block Diagram

The antenna used is a magnetic loop, made by wrapping wire in a circle so that magnetic field changes create small currents in the antenna. The antenna can be made arbitrarily large or small (larger antennas will be more sensitive), the only restriction on the antenna is that the resistance of the wire loop be 1 Ω, and the inductance be 1 mH, as the electronics are designed for these characteristics. Further technical detail on different sizes and configurations to make a valid 1 Ω, 1 mH antenna can be found in the Paschal report. The antenna is best placed in a "quiet" area, as far as possible from electromagnetic noise sources like power lines, generators, buildings. Since the antenna is built from a planar loop of wire, it will only capture signals propagating with a magnetic field component in the plane. Thus, in order to capture signals from all azimuths, it is necessary to set up two antennas, orthogonal to each other. Generally, one antenna captures the North/South component of incoming signals, and a second antenna captures the East/West component. It is possible, however, to orient the two antennae in any desired configuration. All the signal electronics in the preamp and line receiver are designed for two antenna channels, though one can be left out if it is not needed for a particular application. So this receiver is not designed to capture signals with three degrees of freedom (ie, like nearfield radiation).

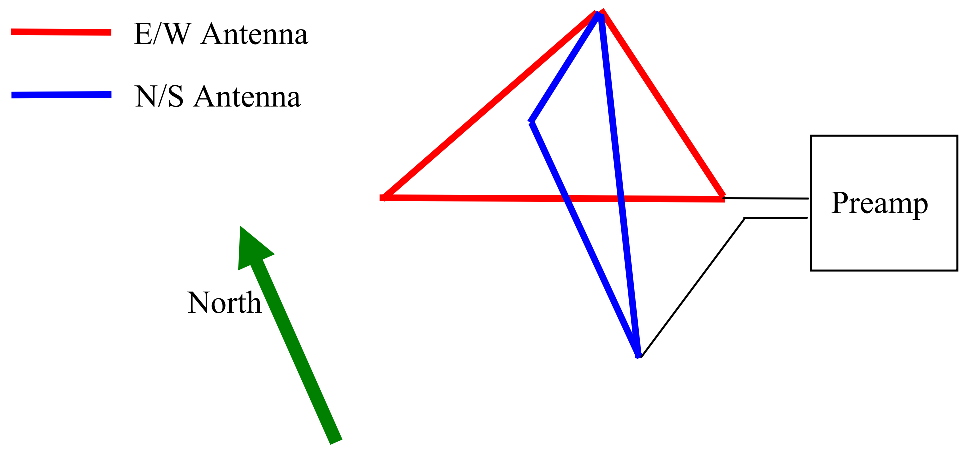


Figure 2: VLF Two Channel Orthogonal Magnetic Loop Antenna Configuration

Figure 3 illustrates the block diagram of the preamplifier. The preamp should be placed as close as possible to the antenna, so that small signals aren't attenuated over long cables. Since the antenna is outdoors, the preamplifier must be housed in a weatherproof container. The preamplifier's electronic operation is relatively simple compared to the line receiver's. This is intentional, in order to minimize interference into the antenna. The main amplification in the preamp comes from a differential amplifier designed with discrete transistors. A very important component, though, is a custom built transformer between the antenna and the transistors that closely matches the 1 Ω resistance of the antenna to the small signal resistance of the transistor circuit. Following the transistor amplifier, a number of op-amps buffer the signal, set the low frequency response cutoff, and the gain. An RFI (radio frequency interference) suppression circuit is added to the front end. Made from an LC low pass filter, this circuit ensures that high frequency signals like AM/FM radio broadcast do not affect the electronics.

The preamp also includes a calibration circuit to determine the frequency response of the system. The calibration circuit is described in detail in a later section, but it works by injecting a test signal at the very front end of the preamplifier, and the output of the receiver could be read to determine the system's frequency response. The calibration circuit is activated by the line receiver, which provides power to run it.

The preamp is placed inside a NIMA-4 rated weather proof box since it is normally placed outdoors. The preamplifier is connected to the line receiver through a cable that has four pairs of conductors: two for the antenna signals, one for the power signals, one for the calibration signal. Each pair is shielded to prevent crosstalk and interference.

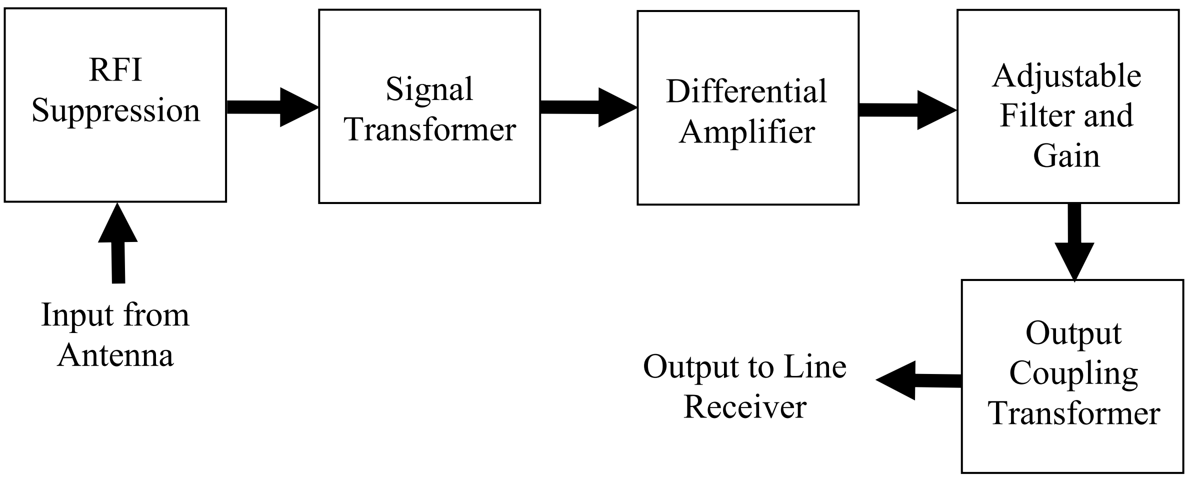


Figure 3: Preamplifier Block Diagram

Preamplifier From Outside

Open Preamplifier Box

The line receiver's operations are noticeably more complicated than the preamp's. The line receiver should be placed 100 ft or more from the preamplifier through a shielded cable, so that the electronics in the line receiver does not emit radiation that couples into the antenna. The line receiver must be placed close to a computer which can record the data coming from it. The line receiver serves many functions, including signal processing, digitization control, GPS management,

power management, and system calibration. The line receiver is placed in a custom built box though it is not designed for outdoor use.

In processing the signal, the line receiver includes a clip protection circuit, which clips the top of signals when they get too strong (and sets of an indicator light). If calibrated correctly, though, this should only be triggered in the event of exceptionally strong signals or an electrical failure. The most important part, though, is an anti-aliasing filter. For most VLF group applications, the data is sampled at 100 kHz, thus the anti-aliasing filter should be fixed between 40 and 50 kHz. A pair of identical filter chips 12 poles total takes care of that filtering.

Line Receiver Front

Line Receiver Back

Line Receiver Inside

One of the key requirements for the 2005 VLF receiver is very high accuracy sampling, in order to synchronize the sampling in different systems and provide precise phase information in narrowband analysis. This requirement is met by providing the ADC card with a low-skew, low-draft clock. The line receiver does this by using a GPS locked signal, and a trim-adjustable 10 MHz oscillator. Using the GPS timing signal (1 Hz), and a feedback circuit, the 10 MHz clock is adjusted so that it is as accurate as possible. The 100 kHz sampling signal is generated from this accurate clock. The details and performance characteristics of this are included later.

The GPS signal needed for this circuit comes in from an antenna and is attached to an on-board card made by Motorola. The GPS antenna does not need to be in a quiet location, but it should have a clear view of much of the sky in order to communicate with GPS satellites. An FPGA in the line receiver communicates with the Motorola board and uses it to synchronize the sampling clock, and to provide a time stamp for all the data through a serial port.

The line receiver is also responsible for providing power to the preamplifier. The power is generated from 60 Hz, 110V AC power by an external power supply inside the line receiver box. If using in an area that does not provide 60 Hz 110 V power, you will need to find a way to convert your power, or to drive the line receiver's DC input voltages directly from an external source. The voltages +/- 15 V are delivered along the same cable that brings the signals from the preamp (the shielding of the cable pairs enables this to be possible without degradation of the data).

Finally, the line receiver controls and activates the calibration circuit in the preamp, by sending a 15 V power signal over the cabling. The FPGA on board also controls this, activating the calibration circuit at predetermined internals by turning on a transistor driver circuit.

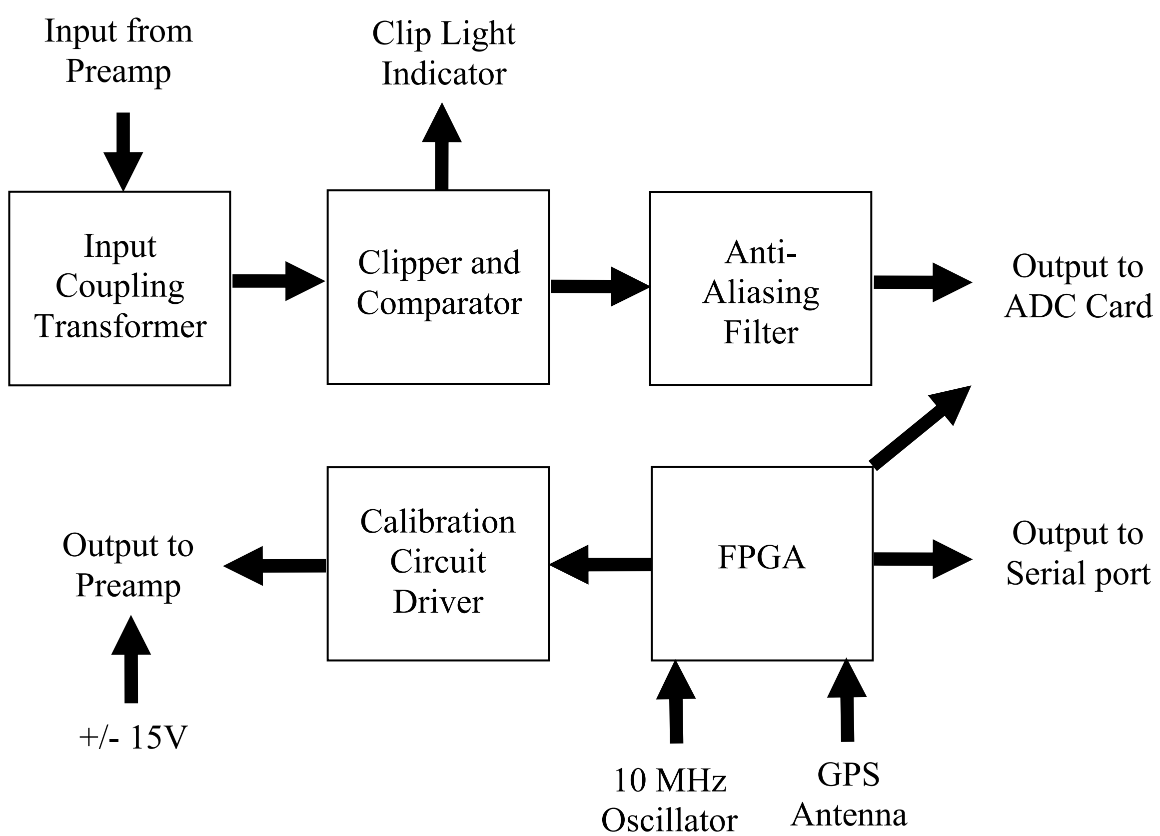


Figure 4: Line Receiver Block Diagram

The data is usually digitized with a card installed in the PC. The card used is made by National Instruments, and goes into a PCI slot in the computer. Alternatively, a PCMCIA version is available for a laptop computer. The PC has installed software, created by the VLF group, that is capable of producing raw MATLAB data files, demodulating and breaking down the data for selected frequencies (narrowband studies), and sending the information over the internet (ftp).

ii. Improvements to the Stanford University 2005 VLF Receiver

The AWESOME monitor includes a number of modifications in electrical performance, mechanical layout, cost, and ease of use. Since some users of the AWESOME receiver may already be familiar with older design iterations, it is helpful to highlight these changes and additions specifically.

<u>Elimination of line driver circuit</u>: The previous VLF receivers contained an elaborate line driver card in the preamplifier, in order to drive the signal over as much as 2000 ft of cabling to the line receiver. In AWESOME, this whole card was eliminated, and the output op-amp in the preamp card was swapped with one that has more output drive ability. This greatly simplifies the design of the preamplifier.

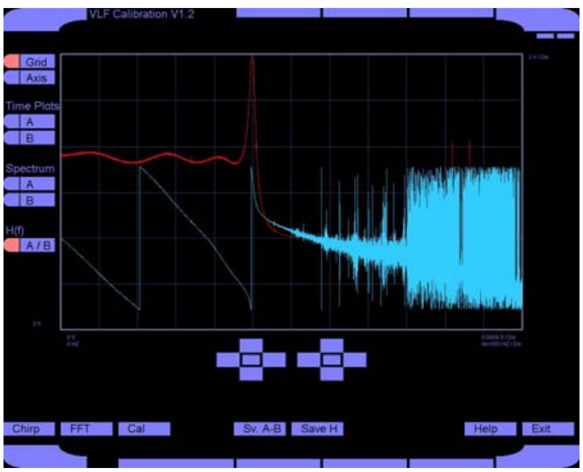
<u>Elimination of 35 V preamp supply</u>: In previous designs, the preamp was powered from a 35 V signal coming from the line receiver. The 35 V was generated in the line receiver directly from 110V AC power. Once in the preamp, this 35 V single ended voltage would then be regulated into a +/- 15 V bipolar supply. The chief disadvantage was that the preamp and line receiver had different grounds (ground for the preamp was at +17.5 V for the line receiver), which made it impossible to probe signals in the preamplifier without shorting out the DC signals.. Instead, the AWESOME receiver sends a direct +/- 15 V signal from the line receiver to the preamplifier. This removes the AC-DC regulation circuit in the line receiver and the DC-DC regulation in the preamp.

<u>Single cable connection between line receiver and preamp</u>: The former VLF receivers had two coaxial BNC cables, one for each channel, connecting the preamplifier to the line receiver. The N/S channel also transmitted the 35 V power signal. This has been replaced with a new four-pair shielded cable made by Belden, the 1217B. Not only has the power signal been decoupled from the transmission line for the signals, but there is now only one cable instead of two, and the 75 Ω impedance of the cable used reduces the signal attenuation for the long cable lengths.

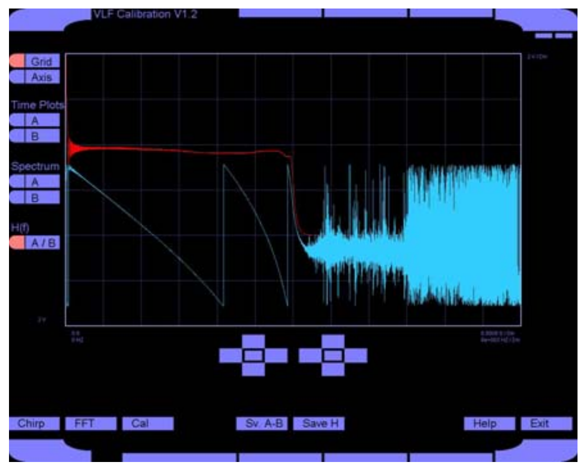
<u>Improvements in low frequency response</u>: Though previous VLF receivers were deployed in places that required measurements of frequencies as small as 30 Hz, a number of undocumented hardware changes were required in order to achieve this response. This is mostly because the older version was designed primarily to be a narrowband system, optimized for the frequency range of 10-40 kHz.

In addition, the line transformers, on either side of the transmission lines, had some peaking at in the frequency response at about 1 kHz and began to rolloff a little below that. AWESOME is designed by default to work at frequencies as low as 30 Hz. The newer version replaces the line transformer with a better one, which has a lower cutoff.

Improvements in high frequency response: Our VLF receiver systems are sampled at 100 kHz, which is why the anti-aliasing filter is set at 40 kHz or so. The new receivers implement this filter with a sharper circuit (LTC1562), which has both a flatter response in the passband, and a sharper brick wall response. As a result, the new anti-aliasing filter raises the bandwidth of useful data to 45-47 kHz. The filter cuts off at 47 kHz, and reaches 100 dB of attenuation by 55 kHz, ensuring that data up to 45 kHz is free of aliasing. These `two pictures show the improved anti-aliasing filtering of the AWESOME monitor. The red line indicates the amplitude, and the blue line indicates the phase.



Old VLF Receiver Frequency Response



New VLF Receiver Frequency Response

Elimination of external GPS clock: The older VLF systems used a GPS receiver made by TrueTime. The key advantage to it was that it provided not only the 1 Hz GPS signal but also a 100 kHz signal (used for sampling) that is synchronized with the GPS signal and thus very exact (as described earlier, this is important in order to get accurate phase information and to compare data from site to site). In the 2005 VLF receiver, this has been eliminated and replaced with a Motorola GPS receiver contained within the line receiver. Though the Motorola GPS receiver does not generate the 100 kHz GPS-synchronized clock, a frequency-locked loop consisting of a 10 MHz oscillator, an FPGA and a D/A converter (all this is detailed later) generates the 100 kHz sampling

signal within the line receiver. The elimination of the external GPS clock saves substantial cost and means one less component to bring and set up at a VLF reception site. Removing the external GPS receiver reduces the physical size of all the equipment, and eliminates a major cost.

<u>Smaller and lighter preamp box</u>: The physical size of the preamp has been shrunk considerably. Formerly placed in a box with 14" x 16" base, and 7" height, the preamp now measures 8" x 10" base and 5" height (about four times less volume).

<u>Smaller, lighter, more stable line receiver box</u>: The line receiver as well was placed in a better box. The old boxes had a 10" x 12" base and 6" height, whereas the new boxes are 7" x 10" with a 5" height (about half the volume). The new boxes are also more stable, with a two piece design rather than the older completely disassembled frame boxes.

<u>Modular card design and solder-less layout</u>: The AWESOME receiver was designed with ease of testing and debugging in mind. The older version had modular cards in the preamplifier, but the cards were connected to a backplane that required hours to wire up manually to the inputs and to a monitor and control board. The older line receiver placed everything on one large circuit board, with a lot of soldered connections to the box, so that removal of the card for testing or debugging required cutting a dozen or so wires that had to be re-soldered into place later. The new receiver has modular cards for the filter/clip chips in the line receiver (on each channel), and the amplifier cards in the preamp. The modular design also enables a one channel system to be converted to two-channel with much more ease. The input and connections to the box were all made with Molex power plugs rather than permanent soldering. Though a slight contact resistance is introduced (replacing a solder joint resistance), the main boards in each box can be detached from its surroundings and removed in a matter of seconds for easy replacement, testing, or debugging.

<u>New repeatable dummy loop design</u>: A device called a dummy loop emulates the impedance of the antenna and allows test signals to be injected into the VLF system. The previous VLF receiver did not include an accompanying dummy loop design, so dummy loops were often built by hand, individually. As part of the AWESOME package, a new repeatable dummy loop has been completely designed and specified, and a sufficient number will be made so that VLF systems can be readily tested when needed.

New repeatable antenna design: The support structure for the wire loop antennas was previously not documented and often built ad hoc. Accompanying the 2005 VLF receiver is a repeatable, clearly specified method for building two orthogonal antennas and a support structure.

New repeatable hum sniffer design: Site selection is facilitated by the use of a hum sniffer, a miniaturized, portable version of the VLF system. The hum sniffer uses a small antenna, and outputs its signal to a laptop, for quick characterization of electromagnetic environment. The 2005 VLF receiver includes a fully specified and repeatable design for a hum sniffer.

Ease of duplication and change: The AWESOME monitor includes a complete parts list, including price, part number, and manufacturers. Also included is software to reproduce the circuit boards, box, and every other parts. For future VLF receiver needs, as well as for future design changes, individual portions can be modified and change, without redoing the entire system from scratch as was done for this iteration.

E-field preamp; The AWESOME monitor can be adapted for picking up electric field signals instead of or along with magnetic field signals, through the use of a dipole whip antenna, and a different preamp card. This is detailed in the later sections.

iii. Sampling Clock Feedback for Accurate Phase Information

One of the most important features of the 2005 VLF receiver is the ability to produce a very exact 100 kHz signal for sampling. This signal is synchronized with a GPS signal and has very small error. When the error is small enough, the data retrieved can be compared from site to site, and in addition, the phase information gathered in the narrowband analysis becomes much more exact. Older versions used an external GPS clock made by TrueTime to provide the 100 kHz signal, but the 2005 model introduces a frequency locked loop to achieve the same result. Figure 5 shows the hardware block diagram

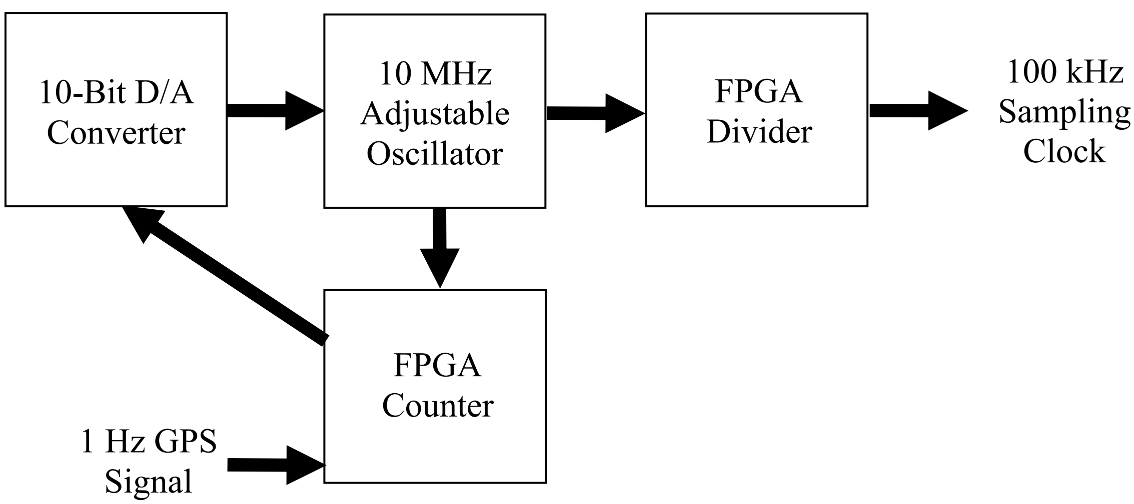


Figure 5: Clock Maintenance Circuit

The FPGA is the main component here. It counts cycles from the 10 MHz oscillator between every 1 Hz GPS pulse, and if the number is greater or less than 10,000,000, the FPGA will change the value of the D/A converter's inputs, which thereby adjust the oscillator accordingly. The accurate 10 MHz clock is divided down to 100 kHz. Since the 10 MHz signal is synchronized every second, as long as the count rate of the oscillator remains at 10,000,000, the frequency remains accurate within 1 Hz, this the error of the sampling clock will be better than 0.1 parts per million (ppm)[1]. Since the error stretches over 1 s (between GPS synchronizations), that corresponds to 100 ns of

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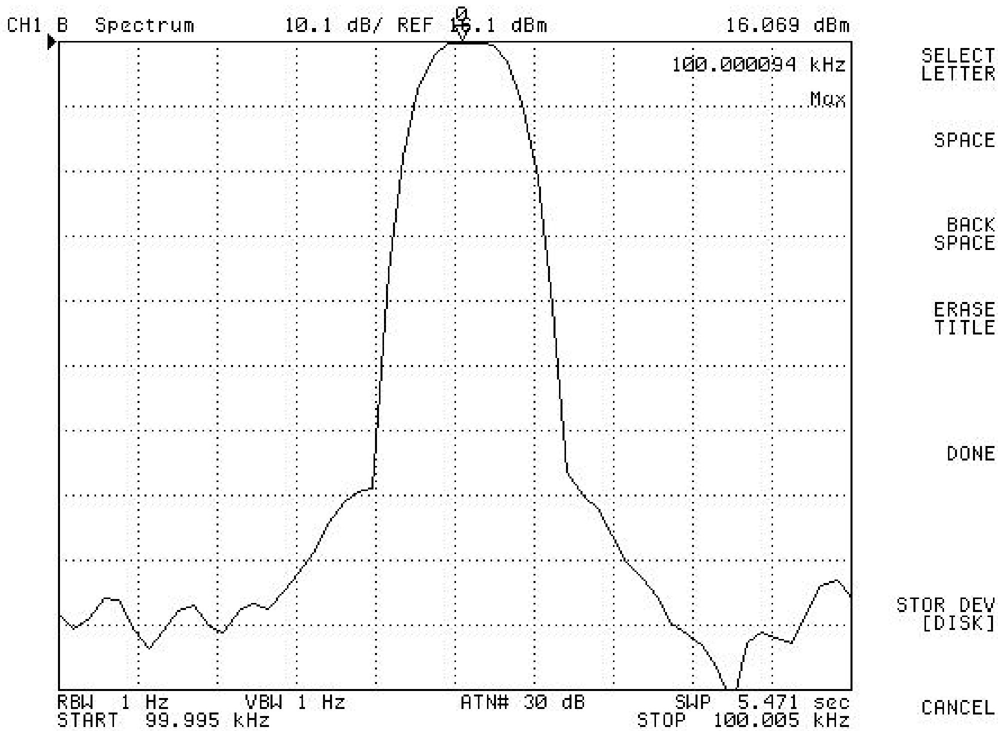
[1] *The feedback should be able to improve further on 0.1 ppm since even fractions of a count per second error will eventually lead to clock adjustment. But since 0.1ppm is already below the GPS error we will stay conservative.*

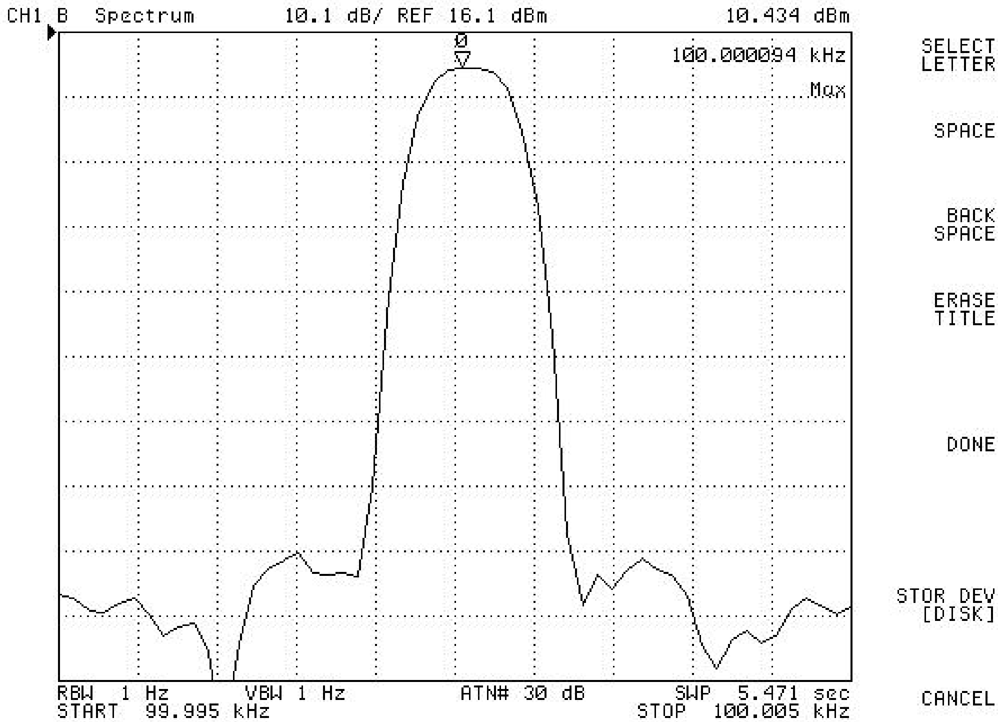
maximum skew at any time. Since the GPS signal itself has a built-in skew of 200 ns, the total error in the sampling clock is 300 ns, or 0.3 ppm.

Since a 20 kHz signal propagates one degree of phase in 111 ns, and the sampling clock's error is 0.3 ppm, or 300 ns, the phase error at 25 kHz will be 300/139 = 2.16º. Two thirds of this error originates from jitter in the GPS signal, which is the limiting error in this scheme. The phase error at higher and lower frequencies will be scaled proportionately to 20 kHz and 2.16º (i.e. a 10 kHz signal has a phase error of 2.16º/2 = 1.08º).

The circuit was tested in two ways: First, the oscillator output was connected to a network analyzer which plotted the frequency content of the 10 MHz signal. When the power was turned on, you could visibly see the frequency start at some amount above or below 10 MHz and then slowly (over a few minutes time) zoom in toward 10 MHz exactly. The plots of the steady states taken from the Network Analyzer are shown below. In a second test, the FPGA was programmed to output a digital signal whenever the 10 MHz clock deviated enough to warrant adjusting the DAC. Additionally, the drift between the two signals could be observed on a fast oscilloscope, and it was observed that the new 100 kpps signal drifted by less than 300 ns at any time.



True Time GPS Frequency Spectrum



Motorola GPS (new) Frequency Spectrum

iv. Hardware Schematics

The following hardware schematics and layout drawings are included:

1. Preamplifier Backplane
2. Preamplifier Gain Card
3. Preamplifier Gain Card Layout
4. Line Receiver Motherboard
5. Line Receiver Motherboard Layout
6. Line Receiver Filter Card
7. Line Receiver Sideboard
8. Electric field preamplifier card

v. Preamp DC Biases

The following diagram shows the DC biases for the preamp transistor circuit. This may be useful for troubleshooting or for future design changes.

vi. Parts List

Here is a parts list for the 2005 Stanford VLF receiver

VLF System

Line Receiver

Qty	Description	Supplier	Part #
1	Motherboard	Advanced Circuits	Custom Made
2	Filter Cards	Advanced Circuits	Custom Made
1	Sideboard	Advanced Circuits	Custom Made
1	External Power Supply	PowerOne	HAD15-0.4-A
1	Box	ProtoCase	Custom Made

Preamp

Qty	Description	Supplier	Part #
1	Backplane	Advanced Circuits	Custom Made
2	Preamp Cards	Advanced Circuits	Custom Made
1	Box	Adalet	JN4XHA-100804

GPS

Qty	Description	Supplier	Part #
1	Vic100 GPS Timing Antenna w/ Pipe Clamp	Synergy Systems	10001339
1	GPS N-connector Cable (50m)	Synergy Systems	
1	10ft 1.5 in PVC piping with connector parts	Home Depot	

Cable Assembly

Qty	Description	Supplier	Part #
1	Four Twisted Pair Shielded Cable (250 ft)	Belden	1217B
2	Amphenol 12 Pin Cable Connector with Sockets	Digikey	97-3106A-20-27S

Antenna

Qty	Description	Supplier	Part #
123 ft	Wire 14 AWG		
2	Amphenol 3 Pin Cable Connector with Rocker	Digikey	MS3106R-10SL-3S

A/D System

Qty	Description	Supplier	Part #
1	NIDAQ Card 6034E	National Instruments	187576C-01
1	50 Pin Cable SH6850	National Instruments	776784-01

Line Receiver

Motherboard

Ref	Value	Description	Supplier	Part #
C1	4.7 nF	Ceramic Capacitor	Digikey	
C2	4.7 nF	Ceramic Capacitor	Digikey	
C3	10 uF	Tantalum Capacitor	Digikey	399-1335-ND
C4	4.7 nF	Ceramic Capacitor	Digikey	
C5	4.7 nF	Ceramic Capacitor	Digikey	
C6	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C7	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C8	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C9	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C10	47 nF	Ceramic Capacitor	Digikey	495-1069-1-ND
C11	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C12	0.33 uF	Ceramic Capacitor	Digikey	399-2174-ND
C13	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C14	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C15	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C16	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C17	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C18	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C19	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C20	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C21	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C22	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C23	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C24	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C25	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C26	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C27	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C28	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C29	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C30	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C31	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C32	Small	Optional - Typically left out		

C33	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C34	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C35	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C36	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C37	1.0 uF	Tantalum Capacitor	Digikey	399-1337-ND
C38	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
C39	0.1 uF	Ceramic Capacitor	Digikey	399-2155-ND
D1	1N4005	Diode	Digikey	1N4005RLOSCT-ND
D2	1N4005	Diode	Digikey	1N4005RLOSCT-ND
D3	1N4148	Diode	Digikey	
J1		12-Pin Power Header	Digikey	WM1629
J2		50-Pin Right Angle Header	Digikey	AHZ50K
J3		0.1" Jumper Header	Digikey	4-103240-0
J4		44-Pin 0.1" Card Edge Connector	Digikey	S1223
J5		10-Pin 0.1" Protected Header	Digikey	A26268
J6		44-Pin 0.1" Card Edge Connector	Digikey	S1223
J7		0.1" Jumper Header	Digikey	4-103240-0
J8		0.1" Jumper Header	Digikey	4-103240-0
J9		0.1" Jumper Header	Digikey	4-103240-0
J10		0.1" Jumper Header	Digikey	4-103240-0
L1	22 uH	Inductor	Digikey	1530B225
L2	22 uH	Inductor	Digikey	1530B225
L3	22 uH	Inductor	Digikey	1530B225
L4	22 uH	Inductor	Digikey	1530B225
Q1	2N3906	PNP Transistor TO-92	Digikey	
Q2	2N3904	NPN Transistor TO-92	Digikey	
R1	4.7 kOhm	1% Metal Film Resistor	Digikey	
R2	12.1 kOhm	1% Metal Film Resistor	Digikey	
R3	N/A	Does not exist		
R4	47 Ohm	1% Metal Film Resistor	Digikey	
R5	N/A	Does not exist		
R6	N/A	Does not exist		
R7	10 kOhm	1% Metal Film Resistor	Digikey	
R8	N/A	Does not exist		
R9	75 Ohm	1% Metal Film Resistor	Digikey	
R10	75 Ohm	1% Metal Film Resistor	Digikey	
R11	953 Ohm	1% Metal Film Resistor	Digikey	
R12	1 kOhm	1% Metal Film Resistor	Digikey	
R13	250 Ohm	1% Metal Film Resistor	Digikey	
R14	250 Ohm	1% Metal Film Resistor	Digikey	
R15	1 kOhm	1% Metal Film Resistor	Digikey	
R16	1 kOhm	1% Metal Film Resistor	Digikey	
R17	1 kOhm	1% Metal Film Resistor	Digikey	
R18	1 kOhm	1% Metal Film Resistor	Digikey	
R19	1 kOhm	1% Metal Film Resistor	Digikey	
R20	410 Ohm	1% Metal Film Resistor	Digikey	

R21	350 Ohm	1% Metal Film Resistor	Digikey	
T1		70.7 Line Audio Transformer	Stancor	A-8096
T2		70.7 Line Audio Transformer	Stancor	A-8096
TP1		Test Point	Digikey	
U1		Voltage Regulator uA7805 TO-220	Digikey	296-13996-5-ND
U2		Voltage Regulator uA7905 TO-220	Digikey	LM7905CTNS-ND
U3		4 Pin Power Header	Digikey	WM1626
U4		Inverters 74ACT04	Digikey	
U5		RS232 Chip Max3323 DIP	Maxim	MAX2232
U6		10-Bit D/A Converter THS5651 SOIC	Digikey	296-2992-5-ND
U7		10-Pin 0.1" Protected Header	Digikey	A26268
U8		9 Pin Serial Connector	Digikey	309M
U9		44-Pin PLCC Socket	Digikey	AE7328
U10		10 MHz Oscillator DIP	Vectron	VTA1-1B1-10M000
U11		Inverters 74HC04	Digikey	296-12772-5-ND
U12		10-Pin 0.05" Header	Samtec	SFMC-105-01-S-D
U13		Voltage Regulator LM317 TO-220	Digikey	LM317HVT-ND
U14		Voltage Regulator LM317 TO-220	Digikey	-
U9*		Altera Max 7000AE EPM7064AE	Arrow	EPM7064AELC44-7
U12*		Motorola GPS M12+ Timer Card	Synergy Systems	

LTC1562 Filter Card

Ref	Value	Description	Supplier	Part #
C1	10 pF	Ceramic Capacitor	Digikey	
C2	0.1 uF	Ceramic Capacitor	Digikey	
C3	1.0 uF	Tantalum Capacitor	Digikey	
C4	0.1 uF	Ceramic Capacitor	Digikey	
C5	1.0 uF	Tantalum Capacitor	Digikey	
C6	4.7 uF	Ceramic Capacitor	Digikey	
C7	47 pF	Ceramic Capacitor	Digikey	
C8	0.1 uF	Ceramic Capacitor	Digikey	
C9	1.0 uF	Tantalum Capacitor	Digikey	
C10	0.1 uF	Ceramic Capacitor	Digikey	
C11	1.0 uF	Tantalum Capacitor	Digikey	
C12	39 pF	Ceramic Capacitor	Digikey	
C13	27 pF	Ceramic Capacitor	Digikey	
C14	390 pF	Ceramic Capacitor	Digikey	
C15	0.1 uF	Ceramic Capacitor	Digikey	
C16	1.0 uF	Tantalum Capacitor	Digikey	
C17	0.1 uF	Ceramic Capacitor	Digikey	
C18	1.0 uF	Tantalum Capacitor	Digikey	
C19	33 pF	Ceramic Capacitor	Digikey	
C20	0.1 uF	Ceramic Capacitor	Digikey	
C21	1.0 uF	Tantalum Capacitor	Digikey	
C22	0.1 uF	Ceramic Capacitor	Digikey	
C23	1.0 uF	Tantalum Capacitor	Digikey	

C24	8.2 pF	Ceramic Capacitor	Digikey	
C25	15 pF	Ceramic Capacitor	Digikey	
C26	0.1 uF	Ceramic Capacitor	Digikey	
C27	1.0 uF	Tantalum Capacitor	Digikey	
C28	0.1 uF	Ceramic Capacitor	Digikey	
C29	1.0 uF	Tantalum Capacitor	Digikey	
C30	0.1 uF	Ceramic Capacitor	Digikey	
C31	1.0 uF	Tantalum Capacitor	Digikey	
C32	0.1 uF	Ceramic Capacitor	Digikey	
C33	1.0 uF	Tantalum Capacitor	Digikey	
D1	1N4005	Multiplexer SOIC-20	Digikey	
D2	1N4005	Multiplexer SOIC-20	Digikey	
D3	1N4005	4082	Digikey	
D4	1N4005	Multiplexer SOIC-20	Digikey	
R1	20 kOhm	1% Metal Film Resistor	Digikey	
R2	130 kOhm	1% Metal Film Resistor	Digikey	
R3	10 kOhm	1% Metal Film Resistor	Digikey	
R4	150 kOhm	1% Metal Film Resistor	Digikey	
R5	75 kOhm	1% Metal Film Resistor	Digikey	
R6	133 kOhm	1% Metal Film Resistor	Digikey	
R7	40.2 kOhm	1% Metal Film Resistor	Digikey	
R8	60.4 kOhm	1% Metal Film Resistor	Digikey	
R9	5 kOhm	1% Metal Film Resistor	Digikey	
R10	47 Ohm	1% Metal Film Resistor	Digikey	
R11	1.75 kOhm	1% Metal Film Resistor	Digikey	
R12	56.2 kOhm	1% Metal Film Resistor	Digikey	
R13	105 kOhm	1% Metal Film Resistor	Digikey	
R14	5 kOhm	1% Metal Film Resistor	Digikey	
R15	210 kOhm	1% Metal Film Resistor	Digikey	
R16	48.7 kOhm	1% Metal Film Resistor	Digikey	
R17	20 kOhm	1% Metal Film Resistor	Digikey	
R18	107 kOhm	1% Metal Film Resistor	Digikey	
R19	105 kOhm	1% Metal Film Resistor	Digikey	
R20	3 kOhm	1% Metal Film Resistor	Digikey	
R21	3.9 kOhm	1% Metal Film Resistor	Digikey	
R22	4 kOhm	1% Metal Film Resistor	Digikey	
R23	3 kOhm	1% Metal Film Resistor	Digikey	
R24	3.9 kOhm	1% Metal Film Resistor	Digikey	
R25	13.7	1% Metal Film Resistor	Digikey	

	kOhm			
R26	150 kOhm	1% Metal Film Resistor	Digikey	
R27	316 kOhm	1% Metal Film Resistor	Digikey	
R28	45.3 kOhm	1% Metal Film Resistor	Digikey	
R29	698 kOhm	1% Metal Film Resistor	Digikey	
R30	32.4 kOhm	1% Metal Film Resistor	Digikey	
R31	10 kOhm	1% Metal Film Resistor	Digikey	
R32	10 kOhm	1% Metal Film Resistor	Digikey	
R33	10 kOhm	1% Metal Film Resistor	Digikey	
R34	10 kOhm	1% Metal Film Resistor	Digikey	
R35	20 kOHm	1% Metal Film Resistor	Digikey	
R36	22.6 kOhm	1% Metal Film Resistor	Digikey	
R37	47 Ohm	1% Metal Film Resistor	Digikey	
R38	2.2 kOhm	1% Metal Film Resistor	Digikey	
R39	22.6 kOhm	1% Metal Film Resistor	Digikey	
U1		LTC1562 Filter Chip	Digikey	
U2		LM318 Op-Amp	Digikey	
U3		LM339 Comparator Quad	Digikey	
U4		LTC1562 Filter Chip	Digikey	
U7		BUF634 Buffer Chip	Digikey	
U8		LM318 Op-Amp	Digikey	

Sideboard

Ref	**Value**	**Description**	**Supplier**	**Part #**
D1	LED	Red LED	Digikey	MV3750
D2	LED	Red LED	Digikey	MV3750
D3	LED	Blue LED	Digikey	67-1750
J1		Vertical BNC Connector	Digikey	A24513
J2		Vertical BNC Connector	Digikey	A24513
R1	60 Ohm	1% Metal Film Resistor	Digikey	
R2	270 Ohm	1% Metal Film Resistor	Digikey	
R3	600 Ohm	1% Metal Film Resistor	Digikey	
U2		10-Pin 0.1" Protected Header	Digikey	A26268

Box Assembly Parts

Qty	**Description**	**Supplier**	**Part #**
16	Female Crimp Terminals	Digikey	WM1101
1	12 Pin Receptacle	Digikey	WM1337
1	12-Pin Box Mount Connector	Digikey	97-3102A-20-27P

1	4-Pin Receptacle	Digikey	WM1333
4	Screws 6-32 0.25"		
1	Fuseholder	Digikey	F1488
1	Fuse, Slow Blow 1/8W		
1	60 Hz 110V EMI Filter	Digikey	CCM1101-ND
1	10 Pin Ribbon Cable 6"	Digikey	C3AAT-1006G
1	Power Switch	Digikey	CH755-ND
8	Box Screws		
1	Metal Enclosure for AC Power Input	Home Depot	50169 00500
1	MMCX to N-Type Connector	Synergy Systems	

Preamplifier

Backplane

Ref	Value	Description	Supplier	Part #
C25	10 uF	Tantalum Capacitor	Digikey	
C26	0.1 uF	Ceramic Capacitor	Digikey	
D1	1N4005	Diode	Digikey	
D2	LED	Red LED	Digikey	MV3750
D3	LED	Red LED	Digikey	MV3750
D4	LED	Red LED	Digikey	MV3750
D5	LED	Red LED	Digikey	MV3750
J1		12-Pin Power Header	Digikey	WM1629
J2		44 Pin 0.156" Card Edge Connector	Digikey	S5223
J3		44 Pin 0.156" Card Edge Connector	Digikey	S5223
J8		4-Pin Power Header	Digikey	WM1626
J9		4-Pin Power Header	Digikey	WM1626
R1	1.75 kOhm	1% Metal Film Resistor	Digikey	
R2	1.75 kOHm	1% Metal Film Resistor	Digikey	
R3	200 Ohm	1% Metal Film Resistor	Digikey	
R4	200 Ohm	1% Metal Film Resistor	Digikey	
R5	200 Ohm	1% Metal Film Resistor	Digikey	
R6	200 Ohm	1% Metal Film Resistor	Digikey	
T1		25 Volt Audio Line Transformer	Stancor	A8096
T2		25 Volt Audio Line Transformer	Stancor	A8096
U1		Monitor Switch	Digikey	EG1951
U2		Voltage Regulator uA7805 TO-220	Digikey	296-13996-5-ND

Preamp Card

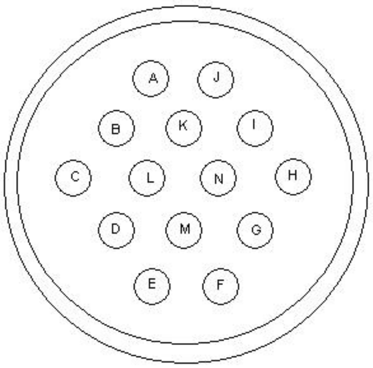
Ref	Value	Description	Supplier	Part #
C1	22 nF	Ceramic Capacitor	Digikey	399-2006-ND
C2	22 nF	Ceramic Capacitor	Digikey	399-2006-ND
C3	22 nF	Ceramic Capacitor	Digikey	399-2006-ND
C4	22 nF	Ceramic Capacitor	Digikey	399-2006-ND
C5	22 uF	Tantalum Capacitor	Digikey	399-1531-ND
C6	22 uF	Tantalum Capacitor	Digikey	399-1531-ND
C7	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C8	10 pF	Ceramic Capacitor	Digikey	399-1888-ND
C9	10 pF	Ceramic Capacitor	Digikey	399-1888-ND
C10	22 uF	Tantalum Capacitor	Digikey	399-1531-ND
C11	0.47 uF	Tantalum Capacitor	Digikey	399-1443-ND
C12	10 nF	Polyprolylene Capacitor	Digikey	
C13	3.3 nF	Ceramic Capacitor	Digikey	399-2001-ND
C14	3.3 nF	Ceramic Capacitor	Digikey	399-2001-ND
C15	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C16	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C17	3.3 nF	Ceramic Capacitor	Digikey	399-2001-ND
C18	3.3 nF	Ceramic Capacitor	Digikey	399-2001-ND
C19	4.7 uF	Ceramic Capacitor	Digikey	399-1302-ND
C20	27 pF	Ceramic Capacitor	Digikey	399-1891-ND
C21	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C22	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C23	4.7 uF	Ceramic Capacitor	Digikey	399-1302-ND
C24	1.0 uF	Tantalum Capacitor	Digikey	
C25	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C26	1.0 uF	Tantalum Capacitor	Digikey	
C27	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C28	22 uF	Tantalum Capacitor	Digikey	399-1531-ND
C29	22 uF	Tantalum Capacitor	Digikey	399-1531-ND
C30	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C31	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C32	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C33	10 uF	Tantalum Capacitor	Digikey	
C34	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C35	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C36	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
C37	0.1 uF	Ceramic Capacitor	Digikey	399-2054-ND
D1	1N4148	Diode	Digikey	
D2	1N4148	Diode	Digikey	
D3	1N4148	Diode	Digikey	
J1		0.1" Jumper Header	Digikey	4-103240-0
J4		0.1" Jumper Header	Digikey	4-103240-0
JP2		0.1" Double Jumper Header	Digikey	4-103240-0
L1	10 uH	Inductor	Digikey	
L2	10 uH	Inductor	Digikey	
Q1	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND
Q2	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND

Q3	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND
Q4	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND
Q5	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND
Q6	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND
Q7	2N4250	PNP Bipolar Transistor	Digikey	PN4250-ND
R1	267 kOhm	1% Metal Film Resistor	Digikey	
R2	267 kOhm	1% Metal Film Resistor	Digikey	
R3	200 kOhm	1% Metal Film Resistor	Digikey	
R4	200 kOhm	1% Metal Film Resistor	Digikey	
R5	1.75 kOhm	1% Metal Film Resistor	Digikey	
R6	500 Ohm	Potentiometer	Digikey	
R7	22.6 kOhm	1% Metal Film Resistor	Digikey	
R8	22.6 kOhm	1% Metal Film Resistor	Digikey	
R9	9.09 kOhm	1% Metal Film Resistor	Digikey	
R10	48.7 kOhm	1% Metal Film Resistor	Digikey	
R11	1 MOhm	1% Metal Film Resistor	Digikey	
R12	48.7 kOhm	1% Metal Film Resistor	Digikey	
R13	48.7 kOhm	1% Metal Film Resistor	Digikey	
R14	1 MOhm	1% Metal Film Resistor	Digikey	
R15	267 kOhm	1% Metal Film Resistor	Digikey	
R16	267 kOhm	1% Metal Film Resistor	Digikey	
R17	232 kOhm	1% Metal Film Resistor	Digikey	
R18	232 kOhm	1% Metal Film Resistor	Digikey	
R19	21.5 kOhm	1% Metal Film Resistor	Digikey	
R20	27.4 kOhm	1% Metal Film Resistor	Digikey	
R21	27.4 kOhm	1% Metal Film Resistor	Digikey	
R22	267 kOhm	1% Metal Film Resistor	Digikey	
R23	10 kOHm	1% Metal Film Resistor	Digikey	
R24	11.5 kOHm	1% Metal Film Resistor	Digikey	
R25	4.12 kOhm	1% Metal Film Resistor	Digikey	
R26	26.7 kOhm	1% Metal Film Resistor	Digikey	
R27	Open	Open Circuit - Do Not Populate	Digikey	

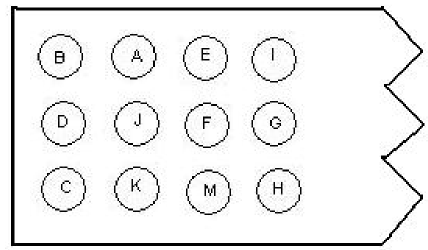
R28	28.7 kOhm	1% Metal Film Resistor	Digikey	
R29	6.81 kOhm	1% Metal Film Resistor	Digikey	
R30	2 kOhm	1% Metal Film Resistor	Digikey	
R31	10 kOhm	1% Metal Film Resistor	Digikey	
R32	61.9 kOhm	1% Metal Film Resistor	Digikey	
R33	100 Ohm	1% Metal Film Resistor	Digikey	
R34	100 kOhm	1% Metal Film Resistor	Digikey	
R35	100 kOhm	1% Metal Film Resistor	Digikey	
R36	100 kOhm	1% Metal Film Resistor	Digikey	
R37	100 kOhm	1% Metal Film Resistor	Digikey	
R38	243 Ohm	1% Metal Film Resistor	Digikey	
R39	1.75 kOhm	1% Metal Film Resistor	Digikey	
R40	243 Ohm	1% Metal Film Resistor	Digikey	
R41	1.75 kOhm	1% Metal Film Resistor	Digikey	
R42	10 kOhm	1% Metal Film Resistor	Digikey	
R43	10 kOhm	1% Metal Film Resistor	Digikey	
R44	100 Ohm	1% Metal Film Resistor	Digikey	
R45	100 Ohm	1% Metal Film Resistor	Digikey	
R46	2.21 kOhm	1% Metal Film Resistor	Digikey	
R47	2.21 kOhm	1% Metal Film Resistor	Digikey	
R48	6.34 kOhm	1% Metal Film Resistor	Digikey	
R49	6.34 kOhm	1% Metal Film Resistor	Digikey	
R50	10 kOhm	1% Metal Film Resistor	Digikey	
R51	5 kOhm	Potentiometer	Digikey	
T1		Custom Made Transformer	Whistler Radio	Turn Ratio 24:548
TP1		Test Point	Digikey	
TP2		Test Point	Digikey	
TP3		Test Point	Digikey	
TP4		Test Point	Digikey	
U1		TL071A Op Amp 8 Pin DIP	Digikey	296-7185-5-ND
U2		TL071A Op Amp 8 Pin DIP	Digikey	296-7185-5-ND
U3		TL071A Op Amp 8 Pin DIP	Digikey	296-7185-5-ND
U4		TL071A Op Amp 8 Pin DIP	Digikey	296-7185-5-ND
U6		Voltage Regulator LM317 TO-220	Digikey	
U7		Voltage Regulator LM337 TO-220	Digikey	LM337TFS-ND
U8		Switch AGD442 16 Pin DIP	Digikey	
U11		PIC12F629 Microprocessor 8 Pin DIP	Whistler Radio	Custom
U12		8.192 MHz Oscillator	Digikey	
U13		Voltage Regulator uA7805 TO-220	Digikey	

Box Assembly Parts

Qty	Description	Supplier	Part #
20	Female Crimp Terminals (qty 20)	Digikey	WM1101
1	12 Pin Receptacle	Digikey	WM1337
1	12-Pin Box Mount Connector	Digikey	97-3102A-20-27P
2	4-Pin Receptacle	Digikey	WM1333
2	3-Pin Box Mount Connector	Digikey	97-3102A-10SL-3P
4	Screws 10-32 0.25"		

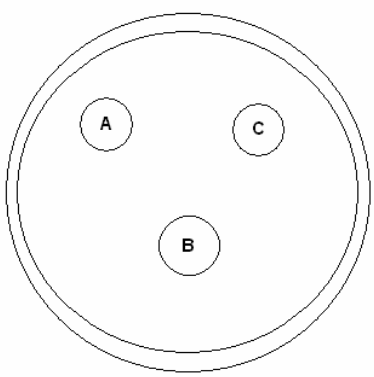


Box Mount 14 Pin Connector
Viewed from inside box

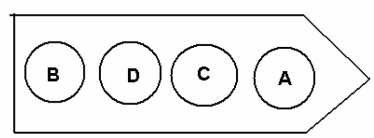


PC Mount 12 Pin Power Header
Viewed from above

A: +15V (Red Pair, Light Wire)
B: Cal+ (Black Pair, Light Wire)
C: Cal Shield (Black Pair, Shield)
D: Cal- (Black Pair, Dark Wire)
E: E/W+ (Orange Pair, Light Wire)
F: E/W- (Orange Pair, Dark Wire)
G: N/S- (Yellow Pair, Dark Wire)
H: N/S Shield (Yellow Pair, Shield)
I: N/S+ (Yellow Pair, Light Wire)
J: -15V (Red Pair, Dark Wire)
K: Gnd (Red Pair, Shield)
L: No Connection
M: E/W Shield (Orange Pair, Shield)
N: No Connection



Box Mount Antenna Conn.
Viewed from inside box



PC Mount 4 Pin Power Header
Viewed from above

A: Antenna+
B: Common
C: Antenna-
D: No Connection

viii. Calibration Circuit

The 2005 VLF receiver includes a calibration circuit so that the frequency response of the system can be measured at any given time. The calibration circuit block diagram is shown in figure 6

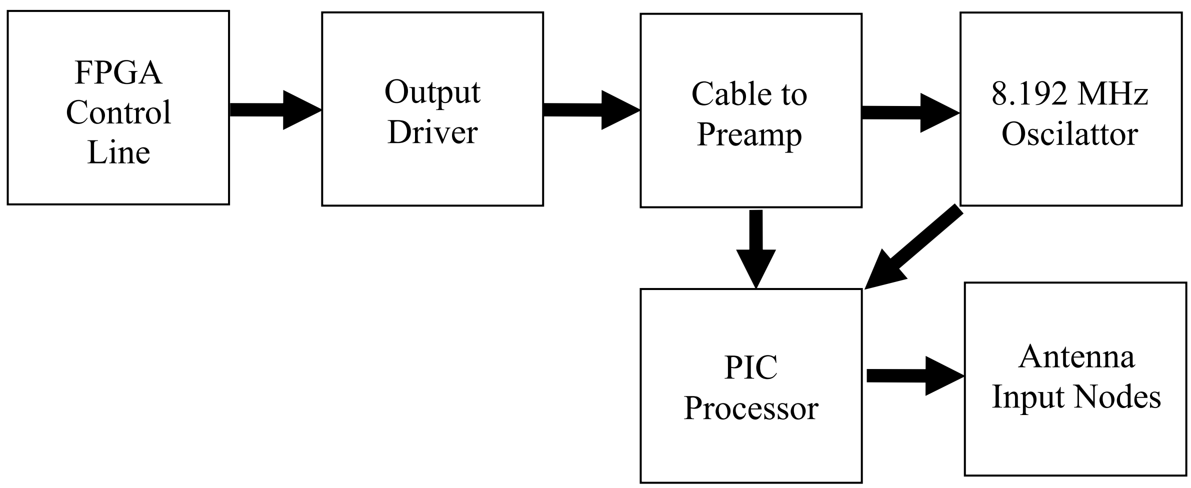


Figure 6: Calibration Circuit Block Diagram

The FPGA controls the calibration circuit, typically turning it on for one second every five minutes, however there are multiple modes selectable with the AuxA and AuxB jumpers. The output driver sends a 15V signal across to the preamp, activating an 8.192 MHz processor and a PIC processor. The PIC processor generates a pseudorandom sequence at 8.192 MHz. The pseudorandom sequence has a Fourier content consisting of uniform height spikes spaced out at 250 Hz. This sequence is applied to the input lines of the preamplifier. It is large enough to overwhelm incoming antenna signals but small enough not to clip the electronics. The calibration signal passes through the entire system. By isolating the 1 second long calibration signal and taking the FFT, it is possible to map out the VLF receiver's response, at discrete multiples of 250 Hz.

The sample spectrogram in the introductory section shows what the calibration data looks like in the data – each vertical red stripe is a calibration tone.

Using a series of short acquisitions, it is thus possible to characterize the system in all possible modes. Detailed instructions can be found in the calibration section.

The calibrator on each preamplifier card must be tuned to provide a known output. The process of tuning can be found in the calibration section.

ix. GPS Communication

Prepared by Justin Tan

GPS Timing Card

GPS Timing for the new HAIL system is internal to the Line Receiver. This reduces equipment costs and bulk.

Manufacturer: Motorola

Model: M12+ Timer

GPS Antenna

Any antenna approved for the Motorola M12+ Timer card is acceptable. The choice depends on the distance to the antenna, and the particular application. The antenna of choice for the HAIL system is the VIC-100 Timing Antenna, which is rated for outdoor use.

Model: VIC-100

Connector Type: N-type

Mounting Option: Pipe clamp

Cable Type: LMR-400 up to 150 feet

GPS Operation

The GPS card communicates through the Line Receiver via standard RS-232 serial communication. It uses Motorola Binary format, which always starts with the "@@" sequence, and ends with "<CR?>LF>" characters. The format is 8 bit payload, no parity, and 1 stop bit. Please refer to the Motorola documentation for more details.

The main command used for the HAIL system is the ASCII Position Information message.

To enable 1 pps output of information: "@@Eq<#01>5<CR><LF>"

To poll then disable 1 pps output: "@@Eq<#00>4<CR><LF>"

Cable Delay

Compensation for cable delay between the antenna and the GPS card can be configured. Please use the provided GPS_Console application to configure cable delay, and test the GPS card. Cable length should be set to the GPS antenna cable length.

Notes:

Once activated, the 1 pps information continually outputs information until power is removed or it is disabled with the appropriate command. The Motorola GPS card has a battery on it, which allows it to retain its settings for several days. If the unit is not outputting data, please use the GPS_Console application to ensure that the GPS card is outputting data.

If the computer is rebooted or turned on while the Line Receiver is on and the software has not been properly shut down, problems with PC mouse operation may occur. This is because the GPS card is communicating to the computer's serial port while the computer is initializing its drivers. If this occurs, turn off the Line Receiver (or disconnect the serial cable), and reboot the computer. Wait for the computer to enter Windows before reconnecting the Line Receiver.

If the GPS Console program does not seem to be working at all, sometimes another program is needed to initialize the COM port. Use a free serial port monitor (Windmill Comdebug) to open then close the port.

Serial settings are:
Data bits: 8
Parity Bit: none
Stop Bit: 1
Baud: 9600

Hardware Source:
Synergy Systems
www.synergy-gps.com

x. FPGA Code

HAIL System FPGA Specifications

FPGA

The HAIL system uses an FPGA to generate sampling signals.

Manufacturer: Altera Corporation

Model: EPM7064AELC44

Package Type: PLCC 44 Pin

IO Voltage: 3.3V

Internal Voltage: 3.3V

Speed Grade: -3 to -7

Source Clock

The HAIL FPGA is driven by a 10 MHz oscillator.

Manufacturer: Vectron International

Model: VTA1-1B1 10MHz (the VTA2 is just a lower profile version, it would also work)

Frequency: 10.000 MHz

Stability: ±1 ppm

Waveform: 0 V – 3.0 V CMOS square wave

Features: Voltage controlled trim

Verilog

Top Level Module: HAIL_LOGIC.v

100 kpps Sampling

Module: GPS_PULSE_100KPPS.v

The HAIL FPGA controls the 100 kpps sampling frequency. It uses the source 10 MHz clock and counts up to 100 to create a 100 kHz square wave signal. The 100 kpps signal is aligned every second to the 1 pps input signal from the Motorola GPS board.

GPS Communication

Module: HAIL_LOGIC..v

GPS communication signals are routed through the FPGA. Currently nothing is done to the signals but it does allow for future control over the Motorola GPS board.

Calibration Tone

Module: HAIL_CALIBRATOR.v

Timing to turn on the calibration signal (see Calibration Circuit), is controlled by the FPGA. It uses a series of counters driven by the GPS 1 pps signal to turn on the cal signal periodically. There are currently 3 settings for the calibration period. These are controlled by the auxiliary jumpers on the motherboard.

No jumpers – normal 300 second period operation.
AUXA – once per minute for 0.2 seconds each time.
AUXB – 400 second period (Currently not supported, DO NOT place a jumper on AUXB unless you have read the additional notes section – there is an error on the circuit board)
Note: do not place jumpers on AUXA and AUXB at the same time.

Clock Adjustment

Module: CLOCK_ADJUST.v

To ensure accurate sampling with the 100 kpps signal, the FPGA controls the level of the voltage trim on the 10 MHz source clock. Sending values to an external DAC, the FPGA detects once a second if the count to 100 is short or over, and adjusts the value to the DAC accordingly. The value eventually converges to a value, and usually takes up to 5 minutes to converge. (See Clock Accuracy section)

xi. Antenna Design

The basis of the 2005 VLF receiver is a 1 Ω, 1 mH, antenna. The antenna type is air core magnetic wire loop antenna, which means it consists of a single long wire wrapped one or more times in a loop, in such a way such that the total resistance of the wire loop is 1 Ω, and its self-inductance is 1mH. This introduces a high pass cutoff of 159 Hz due to the electrical properties of the antenna. Magnetic field changes induce electromotive forces in the wire, inducing currents in the loop. The Paschal report lays out several possible configurations of wire that meet these requirements, and derives the physics of current induction. They are reproduced here for convenience

Some Valid Antenna Configurations

	Length	AWG	Turns	Area	Weight	Wire	mV / pT (Input)
Square	16.0 cm	20	47	256 cm^2	0.132 kg	30.1 m	1.20E-02
	56.7 cm	18	21	0.3215 m^2	0.331 kg	47.6 m	6.75E-02
	1.70 m	16	11	2.89 m^2	0.831 kg	74.8 m	3.18E-01
	4.90 m	14	6	24.01 m^2	2.09 kg	117.6 m	1.44E+00
Right Isosceles Triangle	2.60 m	16	12	1.69 m^2	0.838 kg	75.3 m	2.03E-01
	8.39 m	14	6	17.60 m^2	2.15 kg	121.5 m	1.06E+00
	27.3 m	12	3	186.32 m^2	5.56 kg	197.7 m	5.59E+00
	60.7 m	10	2	921.1 m^2	13.1 kg	293.1 m	1.84E+01
	202 m	8	1	10201 m^2	34.5 kg	487.7 m	1.02E+02

There are two shapes of antennae, square and isosceles triangle. The "length" characteristic of the square shape refers to the length of a side. The "length" characteristic of the right isosceles triangle corresponds to the height of the base (which is along the ground). Because it is a right isosceles triangle, the triangle's height is half that of the base. The antenna thus makes a 45° angle at both corners on the ground, and a 90° angle at the top (mast). The AWG column refers to "American wire gauge", a measure of the thickness of the wire used to wind the antenna. A lower AWG means a thicker wire. Naturally, the larger antennae will need thicker wire in order to keep the resistance below 1 Ω. The turns column refers to the number of times around the wire is wrapped, and the last column shows the length of wire required for the antenna loop (of course, you will need to leave some extra length on each side as well, to connect it to the receiver.

Antenna size selection should be made based on the desired sensitivity, analysis of data, and noisiness of site. The larger the antenna, the more sensitive the VLF receiver will be. The sensitivity is proportional to the area of the antenna. For noisier sites, when only narrowband data will be useful, either the 2.89 m^2 square antenna, or the 1.69 m^2 triangular antenna will probably be sufficient, and its smaller size will make it easier to set up. For quieter sites, or broadband sites, you can use the 24.01 m^2 square or the 17.6 m^2 triangle. For very superbly quiet sites, and when only the best in sensitivity is desired, you can use the 921 m^2 triangular antenna, but of course this will require a lot of effort to hold in place mechanically. The 10201 m2 triangular antenna is probably too big for any application unless you are able to affix it to a permanent structure, but not one that is anywhere close to electromagnetic interference sources.

The antenna should be oriented in a consistent, repeatable, and documented fashion, in order for data from all different sites to be compared. We recommend orienting the antenna in the following fashion: Align the NS antenna so that the loop is in the NS plane, this can be either magnetic north or geographic north. You will need a compass or a GPS device to align it properly, or some way to determine direction to within a few degrees of accuracy. The other antenna should then be aligned along the EW direction, and the orthogonality of the two antennae should be checked with a T-square.

To ensure that the polarity of the antennae is consistent from site to site, we recommend orienting the +/- connections as follows: When you are standing to the north of the EW antenna, looking south at it, if you follow the antenna loop from the + side to the – side, the antenna loop should be clockwise. When you are standing to the east of the NS antenna, looking west at it, following the + connection to the – connection should go clockwise. Connect the antenna to the preamp using these configurations.

Design of an apparatus to physically support the antenna loops should be based on the specifics of the site – the weather, antenna size, ground condition, length of setup, etc. However, here is shown a sample design that has been used for the 8.39m^2 triangular base antenna. This design is fairly easy to set up, however may not be so durable for high winds or extreme weather conditions. As such, it is only recommended for sites that will not see overly extreme conditions, or that will be monitored on a regular basis by someone who can repair it if it breaks down.

The next page shows pictures of the antenna. The triangular antenna features a single vertical mast, axxifed to the ground via a wooden board that is bolted down. Four guidewires (two attached just below the top of the mast, two about halfway up the mast), stabilize the mast, and are staked into the ground so that guidewire is taut, but not too tense. Finally, the four antenna loops are locked into place at the top of the mast, stretched out, aligned to the proper directions, and then staked into the ground.

Antenna Mast with Guidewires

Base of Mast Secured to Ground

Here is a complete parts list for this particular antenna design

Function	Part Description	Qty
elevate antenna loops on mast	Aluminum poles - square 1.25" OD x 6ft.	3
	Antenna wire loops	2
join sections of mast	18-8 SS hex cap screw. 1/4" - 20 x 3"	6
fix cap screws to mast	18-8 SS Hex nylon insert lock nut	6
attach guy wires and antenna to mast.	wire eyebolt 5/16"-18, 2" shank	10
fix eyebolts to mast	18-8 SS hex nut 5/16" - 18	10
	spring lock washer 5/16"	10

attach guy wires to turnbuckle	jaw 5/16" left hand thread	4
tighten guy wires	galvanized turnbuckle 5/16"	4
quick clip guy wires to mast eyebolts	316SS spring snap	6
guy wires	vinyl coated steel rope (2x20ft + 2x15 ft)	70ft
crimp loops in guy wires	oval compression sleeves	8
form loops at ends of guy wires	light duty wire rope thimble	8
stake antenna loops and guy wires into gnd	concrete form board stakes with holes	8

xii. Dummy Loop

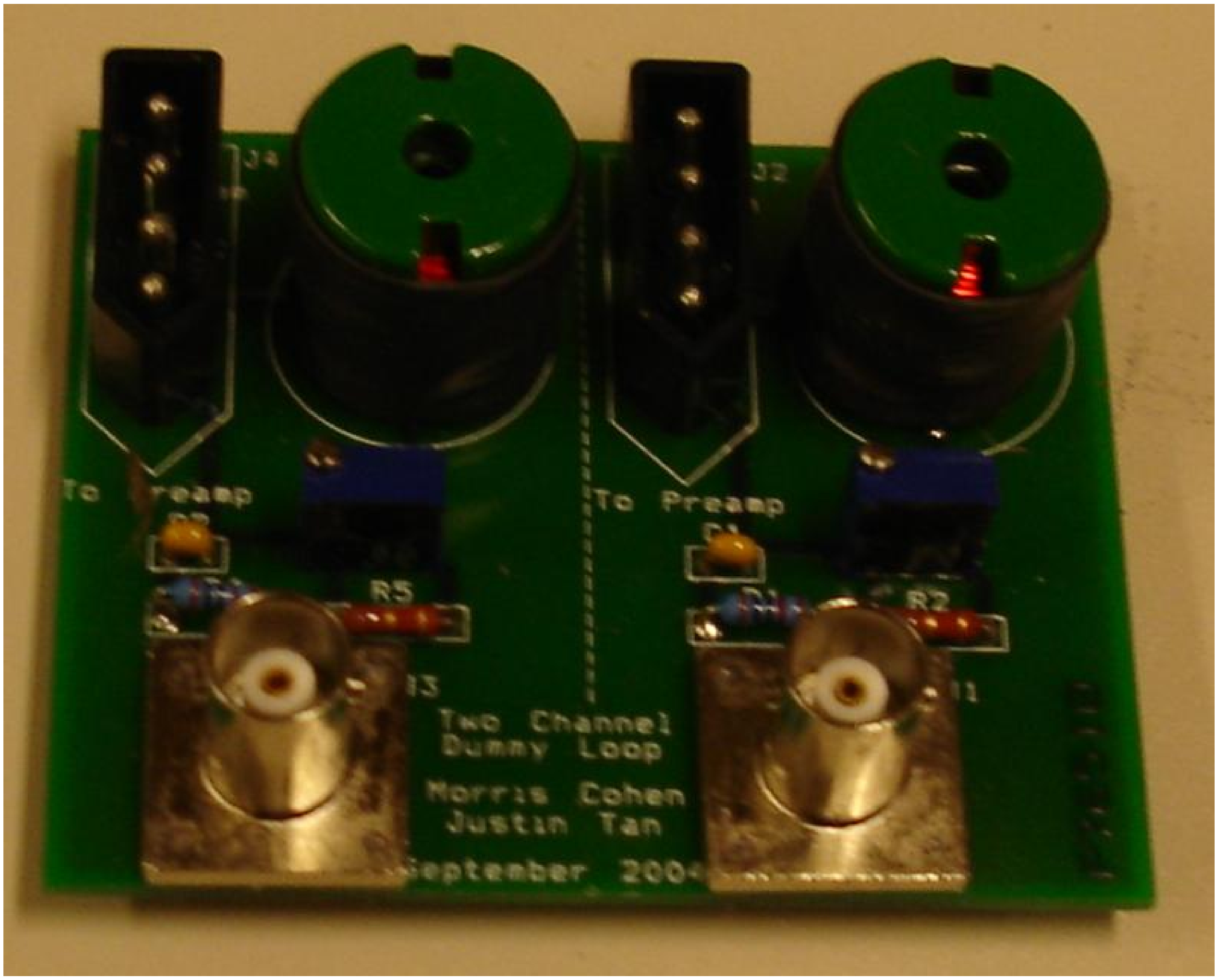
The 2005 VLF Receiver includes a design for a dummy loop. The dummy loop places external signals, like that from a function generator, across an impedance that is equivalent to the antenna's. It is thus possible to inject signals into the input of the preamp for testing and characterization. Aside from testing and calibration, however, a dummy loop is not needed for operation of the 2005 VLF receiver.

The dummy loop functions by splitting the input signal across two series resistors: one large (usually ~10 kΩ and one small (1 Ω of the antenna). The smaller corresponds to the antenna impedence. So, to figure out the signal that is placed at the input, apply simple voltage divider rules. If you input a 100 mV signal, split between 1 Ω and 10 kΩ, then the signal applied across the input will be 0.1 * 1/(1 + 10000) ~= 10 uV.

The following pages shows a schematic for the dummy loop, and a complete parts list. Each dummy loop has two input circuits into it, allowing separate signals to be injected into the different channels. Below you will also find pictures of a fully built dummy loop, and a parts list.

Dummy Loop				
Electrical Components				
Ref	**Value**	**Description**	**Supplier**	**Part #**
C1	0.1 uF	Ceramic Capacitor	Digikey	
C2	0.1 uF	Ceramic Capacitor	Digikey	
R1	10 kOhm	1% Metal Film Resistor	Digikey	
R2	1.1 Ohm	1% Metal Film Resistor	Digikey	
R3	10 Ohm Pot	10 Turn Potentiometer	Digikey	
R4	10 kOhm	1% Metal Film Resistor	Digikey	
R5	1.1 Ohm	1% Metal Film Resistor	Digikey	
R6	10 Ohm Pot	10 Turn Potentiometer	Digikey	
J1		Vertical BNC Post	Digikey	A24513
J2		Four Pin Power Header	Digikey	WM1626
J3		Vertical BNC Post	Digikey	A24513
J4		Four Pin Power Header	Digikey	WM1626
L1	1 mH	Inductor	Digikey	DN2436

L2	1 mH	Inductor	Digikey	DN2436



The potentiometer is used to adjust the resistance so that it is exactly 1.00 Ohm.

xiii. Hum Sniffer Design

The Hum sniffer is being developed over Summer and Fall 2004 by Ambert Ho, and will be described here in detail upon its completion.

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xiv. Electric Field Reception

The AWESOME monitor includes design for reception of an electric field signal either in addition to, or instead of, magnetic field signals. For this, a different antenna is used, consisting of a dipole and a high-impedence input preamplifier circuit. Electric field reception is considerably more difficult due to the smaller nature of the signals picked up by reasonably sized antennas, making interference a much more difficult entity to get rid of. However, for quiet locations, the following circuitry and antenna can be used. Note that if the dipole antenna is placed too close to the magnetic field antenna, there will likely be coupling between the two. It is recommended to either move the dipole away from the magnetic loops, or place it on top.

The design of the electric field antenna originated in the interferometer project, conducted by Joe Payne in 2002-2003. Katie Braden and Evans Paschal collaborated on the first design. The version that is specified here for AWESOME was redeveloped and redesigned by Nancy El-Sakkary in Summer 2005. Below you will find a parts list and schematic for the electric field reception system.

xv. Testing and Set-up

Once the antenna is successfully set up, the process of connecting the 2005 Stanford VLF Receiver and readying it for acquisitions is as follows:

1. Plug in the computer and monitor, and connect the mouse and keyboard. Make sure the appropriate hardware in installed, including a DVD burner (if necessary) and the NI-DAQ PCI card. Make sure all necessary supporting software is installed on the computer…..including StanfordDAQ, an appropriate DVD burning software, the NI-DAQ software, and Matlab.
2. Set up icons on the desktop for the DAQSoftware program, for Matlab, for the DVD burning software, and for the Data folder.
3. Create a text file with the sentence "A Reboot has Occurred". Place this text file in the programs/startup folder in your Windows XP start menu.
4. Place a shortcut to the StanfordDAQ program in the programs/startup folder in your Windows XP start menu.
5. Open the line receiver (in the red box) and make sure that all screws are tightened, all cards are in place, all connectors are in tightly, the jumper settings are correct. Place the cover on the line receiver but do not screw it shut until testing and calibration is complete, as you will need access to the inside of the line receiver. Make sure there is a working fuse already installed.
6. Attach the line receiver to the computer with two cables: A nullmodem serial cable, and an ADC cable which has blue 50-pin connectors on the ends. Both these slots should be labeled on the back of the preamplifier, and should fir it exactly one slow on the back of the acquisition PC.
7. Connect the GPS antenna via the N-Type cable to the connector on the back of the line receiver.
8. Plug in and then turn on the line receiver.
9. Open the "VLF DAQ" program on the PC. Within a second or two, you should see all the GPS coordinates, times, displayed. If the system has been cold for a long time, it may take a few minutes for the GPS card to locate enough GPS receivers to know the time and

location. The "time quality" field reflects on the number of satellites found by the GPS card.

10. Run a test acquisition using the instructions described in the software guide. Make sure that the acquisition begins and ends at the proper time and that the correct files appear in the data directory.
11. Open up the preamplifier (in the silver box), and check to make sure all screws are tight, no chips or part have fallen out or come loose. If they have, tighten or replace them again.
12. Connect the preamplifier to the line receiver using the long Belden 1217B cable. This thick four twisted pair shielded cable will transfer power from the line receiver to the preamplifier, and signals from the preamp to the line receiver.
13. Turn the gain switch all the way counterclockwise, on the big baseboard of the preamplifier. The LED next to "30dB" should be illuminated, and the mode from that point can be changed by flipping the switch. All modes that are past 0 dB (which aren't labeled) are also 0 dB, but keep the switch in one of those four positions.
14. Run another test acquisition and again make sure it runs as predicted.
15. Attach a dummy loop to the ends of the preamplifier (the input) and follow the calibration instructions outlined later in this packet. Be sure to check that the preamp cards are balanced before proceeding with the calibration.
16. Replace the dummy loop connection with an antenna connection, and this should complete the setup.

xvi. Calibration and Characterization

All VLF receivers should be characterized in the field, in order for data to be analyzed from site to site with a common reference. The calibration should be done only when the entire unit is set up, so that the effects of the particular antenna, cable, etc, can be included.

All calibration should be done only when the hardware has been fully tested to work. Specifically, make sure the preamplifier cards are balanced. To balance them, use a multimeter to measure the DC voltage between the TP1 and TP2 test points on the preamp card. This voltage should be zero. If it is not, tune the potentiometer R6 until they are equal. Balancing the two branches of the amplifier circuit will ensure that the noise rejection, specifically at the common mode, is at its peak. Once the circuit has been tuned, put some glue over the potentiometer so that it does not shift to a different setting.

In addition, the calibration circuit must be tuned to provide a known output before calibration can begin. To do this, measure the voltage between (1) the node between R46 and R48, and (2) the node between R47 and R49. Tune the potentiometer R51 until this voltage difference is 2.0 Volts peak to peak. This will generate a 1.00mV RMS signal at each frequency component (spaced out by 250Hz). Once again, put some glue over the potentiometer once this has been set, to ensure that it does not shift.

In order to calibrate, you need to know the antenna properties, and the output corresponding to a known test signal at the input (the calibration signal). Using these parameters, you can convert any voltage at the output to a magnetic field. The calibration signal is generated at the very front end of the preamp card, and is described elsewhere. To activate the calibration mode, enable the Aux1 jumper in the line receiver. This will ensure that a one-second long calibration pulse is injected every 32 seconds. When the Aux1 jumper is removed at the end of testing, the calibration tone will be disabled.

Since capturing the output of this calibration gives the antenna's response, all that is required is to take several recordings that include a calibration pulse. One minute recordings using the software would suffice.

Calibration will require the use of a dummy loop. A dummy loop replicates the impedance of the intended antenna, and enables signals to be injected at the input of the system. The dummy loop's design and functions is described elsewhere. Throughout the characterization process, the dummy loop (or an antenna) should be connected to the preamplifier's input, because system's response (particularly at low frequencies) can be properly estimated only when the VLF input is loaded with the same impedance as it would with an antenna.

The process of calibration in the field requires executing a series of test recordings and observations of the VLF receiver's outputs. Here is a list of the recordings you should make in calibration mode:

1. Both preamp cards inserted
2. *NS preamp card removed*
3. *EW preamp card removed*
4. *Antenna replacing dummy loop*

These four recordings should be taken using the preamp settings you intend to leave it in, as well as any setting you think may be used in the future. So, if you're going to leave it at 0dB gain mode, but may in the future increase the gain to 10dB, you will need to take double the recordings. In addition, repeat for any extra preamp cutoff settings (30Hz, 350Hz, 9kHz) that may be used.

Save all the calibration data and burn it to a CD or DVD. Also, place the recordings in a folder called "Calibration" and store it in the VLF DAQ folder.

Very Low Frequency Data Acquisition Software User Manual

Robert Moore
Edward Kim

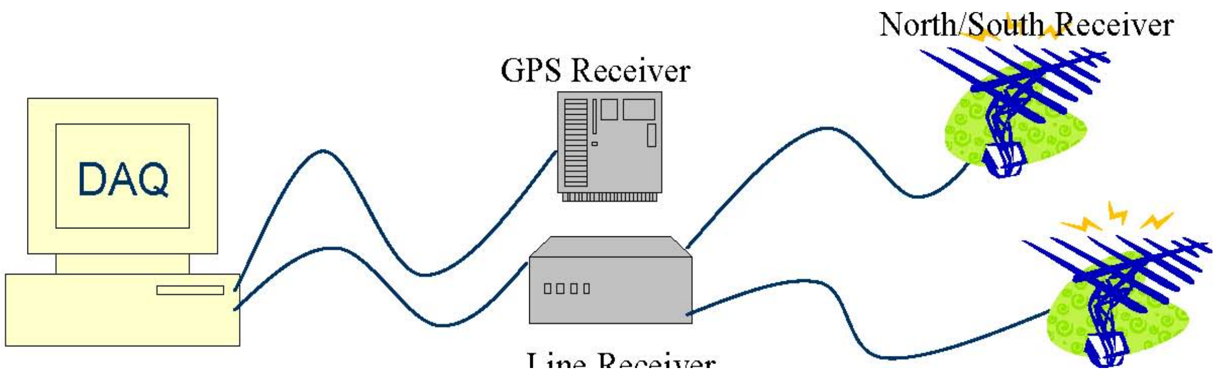
Revised: 6 March 2005

Table of Contents

Introduction

VLF DAQ stands for Very Low Frequency Data Acquisition. It is a data acquisition software designed for capturing and processing broadband and narrowband VLF signals. It works in conjunction with a TrueTime GPS receiver, and 1 or more ADC cards in the PCI slot. Though many different hardware configurations are possible with the software, the most common setup is

illustrated below.



The line receiver gets VLF signals from 2 antennas. There is usually one antenna in the North/South orientation and another in the East/West orientation. These signals are sent to a 200kHz ADC card attached to the PCI slot of the computer. The ADC will capture data from each of the 2 antennas at 100kHz each. The signal from the GPS is fed into the ADC card.

The VLF DAQ software controls precisely when the system should acquire broadband and narrowband data. Upon data acquisition, various user-specified signal processing can be performed on the data. The data is then converted to MATLAB format and may be sent to another computer via FTP.

The VLF DAQ is designed to be robust even when multiple channels of synoptic broadband, continuous broadband, and narrowband are being run simultaneously.

Because different users may want to use the software for different applications, the software was built with scalability in mind. For example, user defined scripts can be run after acquisition of data.

DAQ

GPS Receiver

Line Receiver

North/South Receiver

East/West Receiver

Installing the Software

SYSTEM REQUIREMENTS:

1) Intel Pentium 4 processor PC
2) Microsoft Windows XP
3) 512 MB Ram
4) 10 GB Hard Drive for broadband acquisitions.

RECCOMENDATIONS:

The software is a very CPU intensive program during data acquisitions, so it is recommended that all other CPU heavy programs be turned off while data is being acquired.

REMOTE INSTALL PROCEEDURE (HAIL Software required)

The existing HAIL Software (Demodulator.exe) has the ability to send software updates through the internet via the Communicator program. We will use the existing Demodulator.exe software located in C:\HAILSoftware to remotely install the VLF DAQ software. Instead of updating HAILSoftware, we will use a custom made DownloadNewSoftwareNext.bat to install the new VLF_DAQ software. We will call the computer we would like the software installed on the "remote computer".. We will call the computer that we are installing from (usually located at Stanford) the "server computer". In general, "server computer" will be the hail.stanford.edu computer in 201

1) Make sure Spysweeper is disabled on the remote computer.
2) In "C:\HAILSoftware\hftp.cfg" of the remote computer, edit the variables in hftp.cfg file to the ftp settings on the server computer. In general, the variables should already be assigned correctly.
3) In "C:\HAILSoftware\Listener.ini" of the remote computer, edit the IP address and the port number to the IP address of the server computer and the port number that the Communicator.exe software is listening to. Again, this probably does not to be changed.
4) In the server computer, make sure that the computer contains the correct DownloadNewSoftwareNext.bat file. The correct batch file can be found in the software package under the "manuals_and_examples" directory. The remote computer must download this batch file when step 7 is executed. For the first install of this software, the remote computer will look somewhere in c:\HAILSoftware for the DownloadNewSoftwareNext.bat file. For example, if the remote computer is in Taylor, the Taylor computer will look in C:\HAILSoftwareDownloads\Taylor\HAILSoftware of the remote computer for the batch file. Thus, it is imperative that this batch file is placed in this directory.

We should make sure that DownloadNewSoftwareNext.bat contains the correct commands. The first line "mkdir c:\VLF_DAQ" creates the directory on the remote computer in which the software will be installed to. The next set of lines download the necessary files into the install directory. For example, "c:\HAILSoftware\hftp_get.exe c:\HAILSoftware\hftp_get.cfg \DAQ_SoftwarePackage c:\VLF_DAQ\ dailyCleanup.bat" will copy e:\DAQ_SoftwarePackage\dailyCleanup.bat of the server computer into c:\dailyCleanup.bat of the remote computer.

IMPORTANT NOTE: The drive letter that the remote computer FTPs into must be the same drive that contains \DAQ_SoftwarePackage. In hail.stanford.edu, all incoming FTPs are directed to the E:\. Thus, we must place the DAQ_SoftwarePackage directory in the E:\

After all the program files are copied, the batch file has the following line:
"c:\HAILSoftware\hftp_get.exe c:\HAILSoftware\hftp_get.cfg \DAQ_SoftwarePackage c:\VLF_DAQ\ DownloadNewSoftware.bat"

This line should be included in the batch file only for the FIRST installation of the software package. Any subsequent updated of the software should not contain this line. This line will update the DownloadNewSoftware.bat file that is run on the remote computer anytime "update new software" is called from the Communicator. The new DownloadNewSoftware.bat file (found in \DAQ_SoftwarePackage directory), will instruct the remote computer to look for DownloadNewSoftwareNext.bat file in c:\VLF_DAQ from now on, instead of c:\HAILSoftare. Thus, in subsequent updates of the software, the remote computer will look in the VLF_DAQ directory for DownloadNewSoftwareNext.bat file instead of the HAILSoftware Directory.

The rest of the lines will download the filter files and create the necessary directories for the program to run correctly.

5) Run Demodulator.exe on the remote computer.

6) Run Communicator.exe on the server computer. A connection should be established between the 2 computers on the Communicator software.

7) On the server computer, make sure the connected remote computer is checked and then select "Download New Software" from the pull down menu and then click "administrator send"

8) The remote computer will download DownloadNewSoftwareNext.bat file from somewhere in the c:\HAILSoftware directory. After the file has been downloaded, DownloadNewSoftwareNext.bat file will be executed on the remote computer. The new software will then be installed on the remote computer under c:\VLF_DAQ.

LOCAL INSTALL PROCEEDURE (HAIL Software NOT required)

In the case that HAILSoftware is not installed on the remote computer, or the internet is not accessible in the remote computer, we must install the software locally using a CD with the software on it.

1) Make sure Spysweeper is disabled on the remote computer.

2) Make a directory, preferably c:\VLF_DAQ, where the software should

be installed into. This directory should not have any spaces.

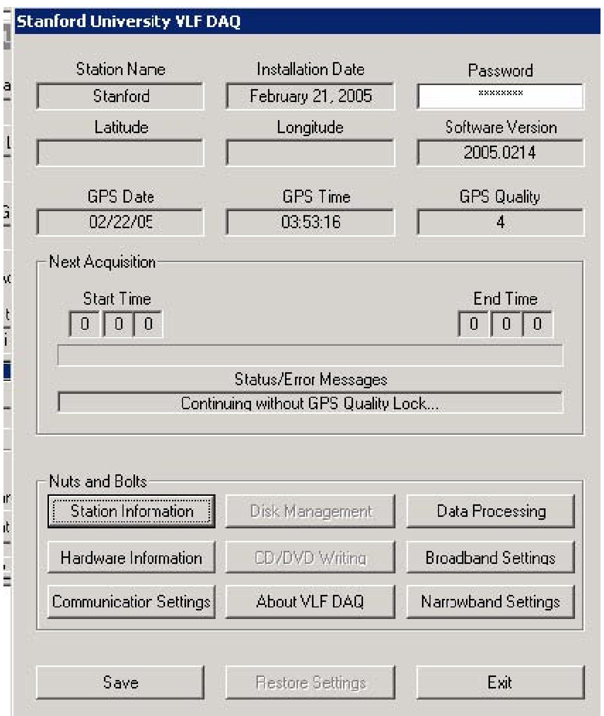
3) Copy the entire contents of the CD into the install directory.

4) Run VLF_DAQ.exe. The startup folder will be updated the first time the software is run.

Overview of the Software

MAIN GUI

The main GUI consists of various status indicator and buttons which open up sub-GUIS.



Station Name is the name of the station that the software is installed on. Installation Date should be the date that the hardware was installed on the computer. Latitude, Longitude, Software Version, GPS Date, GPS Time, GPS Quality will be filled in by the software. If a Motorola GPS system is hooked up, quality is simply the number of satellites the antenna sees. We require at least 3 satellites for a lock to be enabled in the Motorola system. In the truetime GPS is hooked up, quality says "LOCKED" when a GPS lock is acquired.

STATUS INDICATORS

Upon start, the software looks for GPS lock. During this time, no acquisitions may occur. If a GPS lock cannot be found within a certain time, the software will start its acquisition schedule without GPS lock. At the top of the GUI, there are several fields that display the status of the software. These include the station name, installation date, GPS latitude, GPS longitude, GPS date, GPS time, and GPS quality.
In the area entitled "Next Acquisition", the start and end time of the next acquisition is displayed. Below, there is a progress bar which fills up as the acquisition is completed. Below the progress bar, the general status of the software is displayed. Any errors are also displayed in this area as well.

PASSWORD

A password is required to enable any buttons on the DAQ software. This is to prevent unauthorized changes to the software settings.

SAVE

Any changes that are made to the software settings must be followed by a click on the save button in order for changes to take effect. Additionally, the software must be restarted for the saved changes to take effect.

RESTORE SETTINGS

This button restores the software settings to the last saved values.

EXIT

This button will close out any current data acquisitions and end the program.

STATION INFORMATION

This is where the user can specify the various characteristics of the station that the software is installed at. With the exception of StationID and Station name, the fields in this GUI do not directly affect the data acquisition. It should be used as reference when studying data acquired. Station name

indicates the directory that the files will be FTPed to. For example, if "Stanford" is entered as Station Name, the files will be FTPed to the a directory called "Stanford". When narrowband data acquired, it will create matlab filename according to the new filename format:

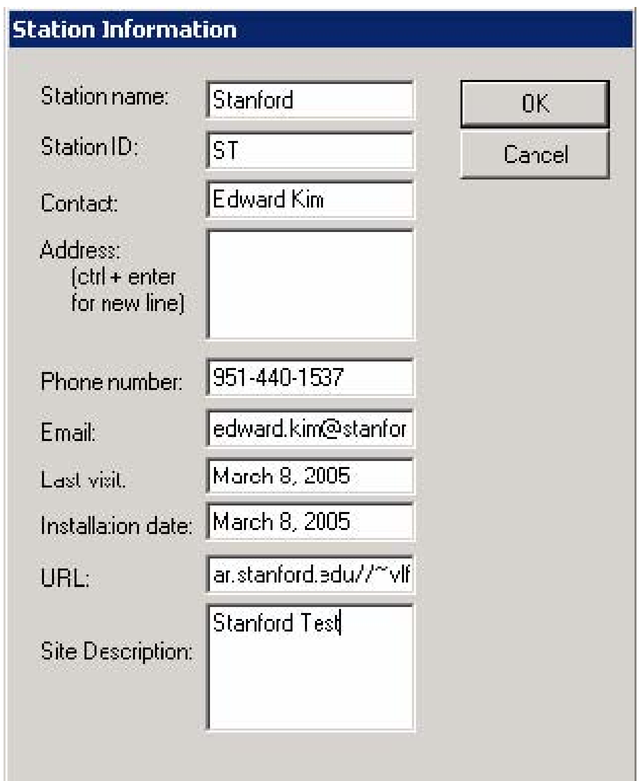
XXYYMMDDHHMMSSZZZ_ACCT.mat

XX – Station ID (from Station Information Dialogue Box YY –Year MM—Month DD—Day HH—Hour MM—Minute SS—Second ZZZ—Transmitter Callsign A—zero-based index of the ADC card that was used CC—zero-based index of the software channel number that was used. T—Amplitude/Phase or Lo/High Resolution. A corresponds to Lo resolution (1hz sampling rate) amplitude, B corresponds to Lo resolution (1hz sampling rate) phase, C corresponds to high resolution amplitude, D corresponds to high resolution phase.

Broadband files are named according to the following convention:

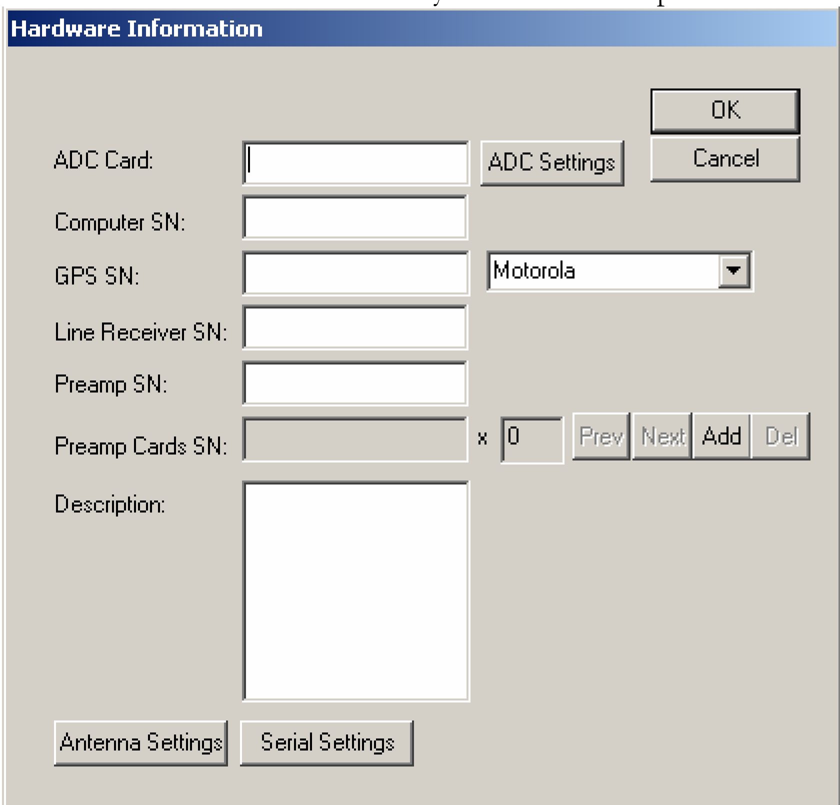
XXYYMMDDHHMMSS_ACC.mat

XX – Station ID (from Station Information Dialogue Box YY –Year MM—Month DD—Day HH—Hour MM—Minute SS—Second A—zero-based index of the ADC card that was used CC—zero-based index of the software channel number that was used.



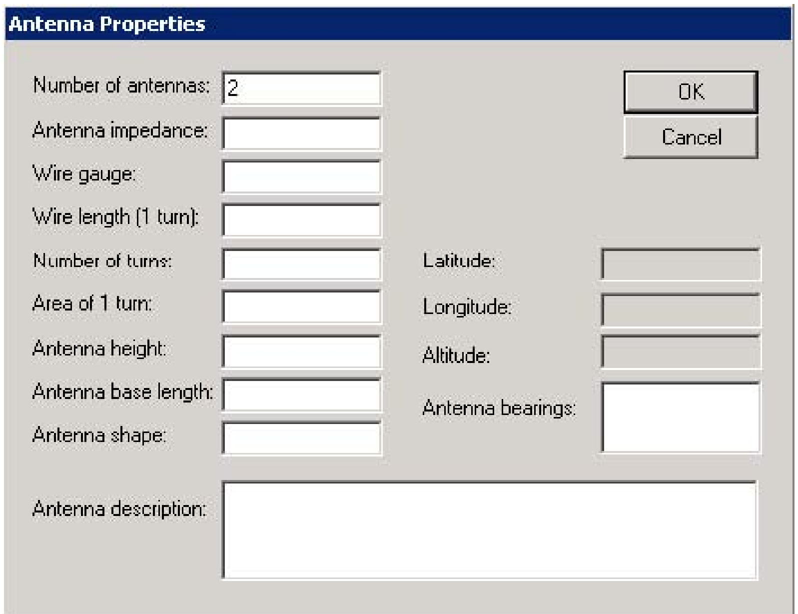
HARDWARE INFORMATION

This is where the user can enter the hardware setup of this station. Note that the user can enter multiple Preamp serial numbers by simply clicking on the "add" button and then using "next" and "prev" to navigate. ADC Card can simply be the model name of the ADC card. Again, the fields in this GUI do not directly affect the data acquisition. They are for informative purposes only. The only exception is the pull down menu in which the user may select the type of GPS sytem—Motorola or TrueTime—that the system is hooked upto.

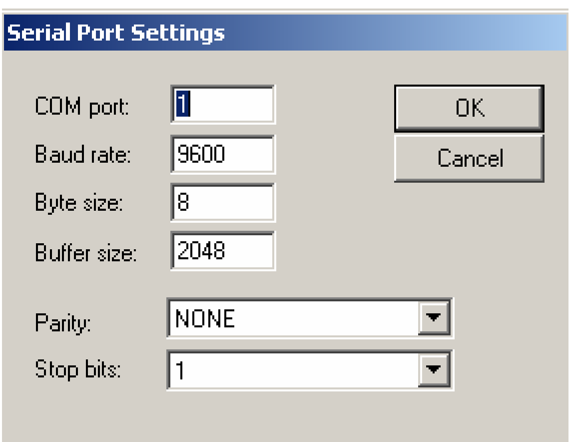


ANTENNA SETTINGS

The user can enter various information about the antenna setup by clicking on the "Antenna Settings" button. The fields in this GUI do not directly affect the data acquisition. It should be used as reference when studying data acquired.



SERIAL SETTINGS



These are settings that the GPS system uses to communicate to the computer through the serial port.

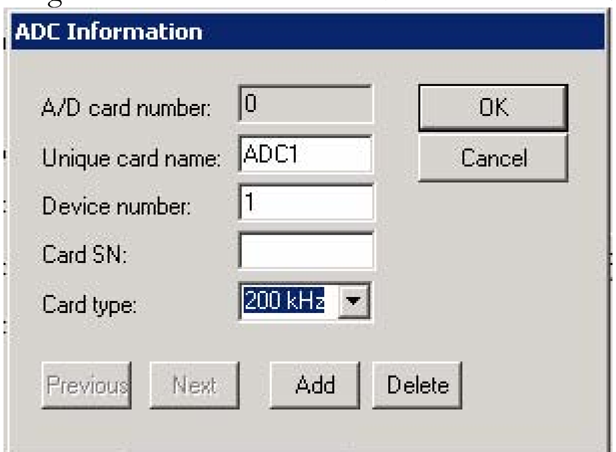
Motorola GPS system should use the following settings:
Baud rate: 9600
Byte size: 8
Buffer size: 2048
Parity: None
Stop bits: 1

Truetime GPS system should use the following settings:

Baud rate: 9600
Byte size: 7
Buffer size: 2048
Parity: even
Stop bits: 1

ADC SETTINGS

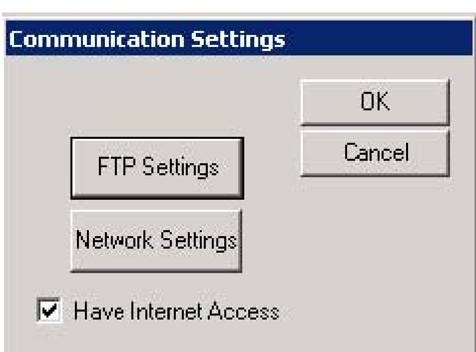
Most important in the hardware information GUI is the ADC sub-GUI. For each ADC card installed in the computer, the user should enter information of the card. The Device number assigned to the ADC card can be found on the NIDAQ configuration utility.



COMMUNICATIONS SETTINGS

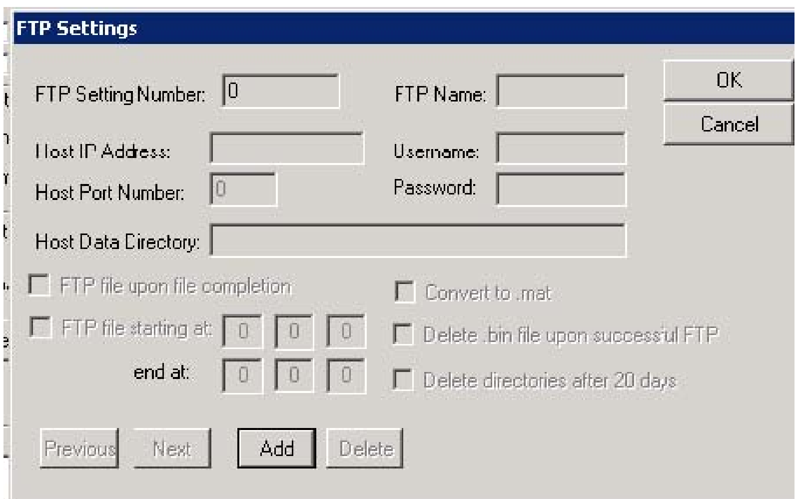
The information in this GUI is important for any features in the software that make use of the Internet.

It is important that the "Have Internet Access" box is checked if internet is available and not checked if it is not available. If this box is not checked, any features requiring internet connectivity will be disabled.



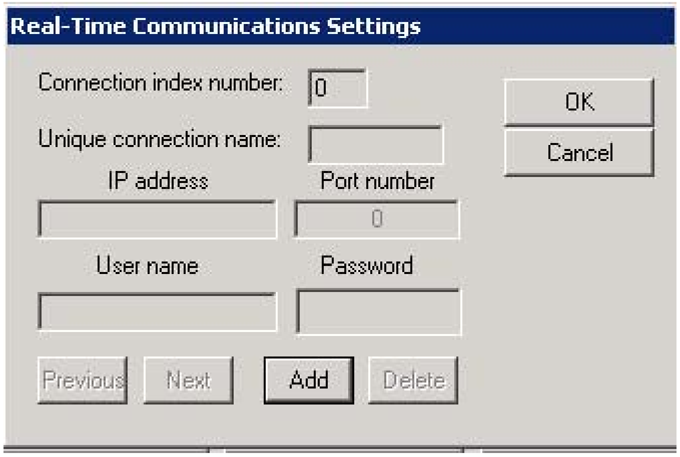
FTP SETTINGS

We would like to FTP data—particularly narrowband data--to a remote site after it is acquired and processed. To do this, the user must add a FTP setting in this GUI. We will call the computer that we would like to FTP data to the “FTP computer”. For each FTP computer, the user must enter the FTP computer’s IP address (i.e. vlf-europe.stanford.edu), port number, user name, password, FTP times, and directory you would like the data to be FTPed to. For each FTP setting, the user should give a name to this setting. The user must also enter the time of the day that they would like the FTP to begin and end. If all the files are FTPed before the end time, the FTP thread will simply close before the end time. If the files are not FTPed within the allotted time frame, the FTP will close and finish up the following day during the next FTP time. We currently support only one FTP setting.



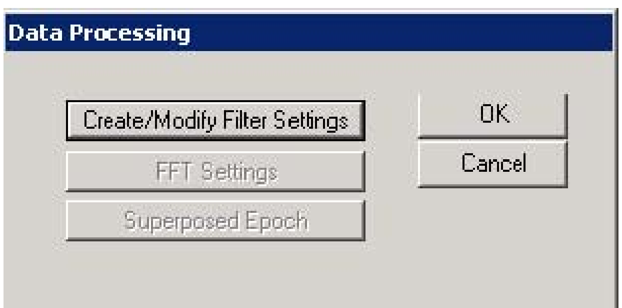
NETWORK SETTINGS

We can control the software over the internet without physical being at the actual computer. We will call the computer we would like to control the “remote computer” and the computer we would like the control the remote computer from the “server computer” In order to have access to the remote computer, we must specify settings on the controlling computer. In particular, we need the IP address and port number of the server computer. The remote computer will then establish a connection with the server computer. The server computer controls the remote computer via the Communicator software. We can, for example, get the status of the remote computer, view and change the settings of the remote computer, restart the remote computer, and command the remote computer to FTP select data. We can also update the software of the remote computer. When we want to view the software settings of the remote computer, the remote computer sends the software settings to the server computer via FTP. For this reason, a user name and password of the server’s FTP is required. We may have multiple server computers controlling remote computer. In this case, we simply click the “add” button to add the information for more server computers.



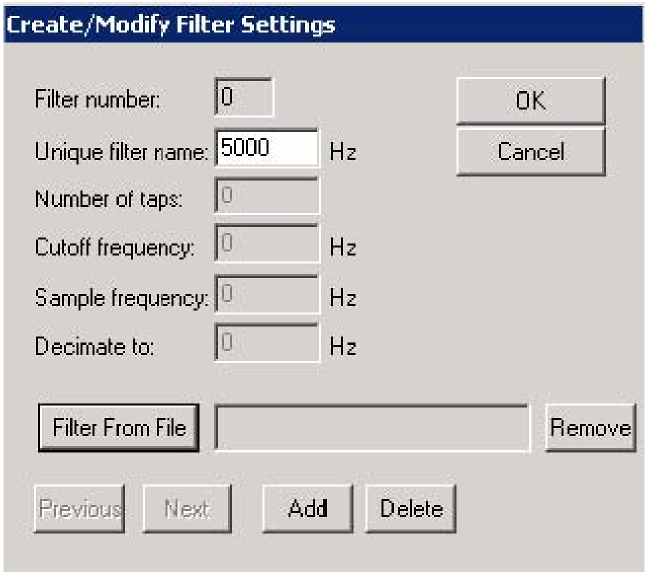
DATA PROCESSING

The data processing GUI contains sub-GUIs that are pertinent to the signal processing that is done on the raw data after it has been acquired.



CREATE/MODIFY FILTER SETTINGS

After data is acquired, we would like it to be filtered. This is done through the filter GUI. To add a filter, simply click on the Add button, then click on the "Filter from File". A dialogue in which the user can select a filter file will be brought up. The filter file simply contains the filter coefficients of a filter—these filter files can be created through matlab. Sample filter files are included on the "filter" folder. For each filter setting, the user should specify a filter name.



BROADBAND

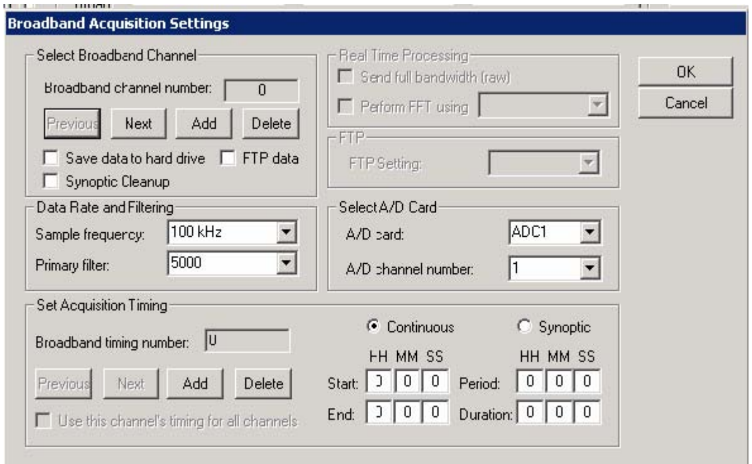
The software supports multiple channels of Broadband data acquisition. To add a channel, simply click on the add button in the Select Broadband Channel section. The save data to disk checkbox, if unchecked, will delete the data on the harddrive after it has been FTPed. The FTP data check box will FTP data using the specified FTP setting, which can be selected from the pull down menu. Note that FTPing of broadband data is not recommended because of the size of the files. The synoptic clean up checkbox, if checked, will run the synopticCleanup.bat file after every synoptic acquisition. The user may edit synopticCleanup.bat file to do anything. For each channel, the user must specify which ADC card to acquire data from. Also, the user must specify which of the 2 channels (usually north/south or east/west) on the ADC card to acquire from. For each channel, the user can specify the sample rate that data will be acquired at. The 100kHz data will be decimated down to this sample rate. For each channel, the user can specify a filter setting to be used from the filter settings created in the filter GUI.

For each channel, the user must specify the timing schedule for this channel. To add a timing schedule, simply click on "add" and enter the times:

Start time--The time that acquisition should start End time--The time that acquisition should end Period--For synoptic acquisitions, the period of acquisition. For continuous acquisitions, the length of data contained in each file. Duration--For synoptic acquisitions, the duration of each period. For continuous acquisitions, the length of data contained in each file.

Note: for continuous acquisitions, the period and duration should be the same.

For example, start time of 3:00, end time of 10:00, period of 1 hour, duration of 5 minutes will acquire data for the first 5 minutes of each hour from 3:00 to 10:00.



NARROWBAND

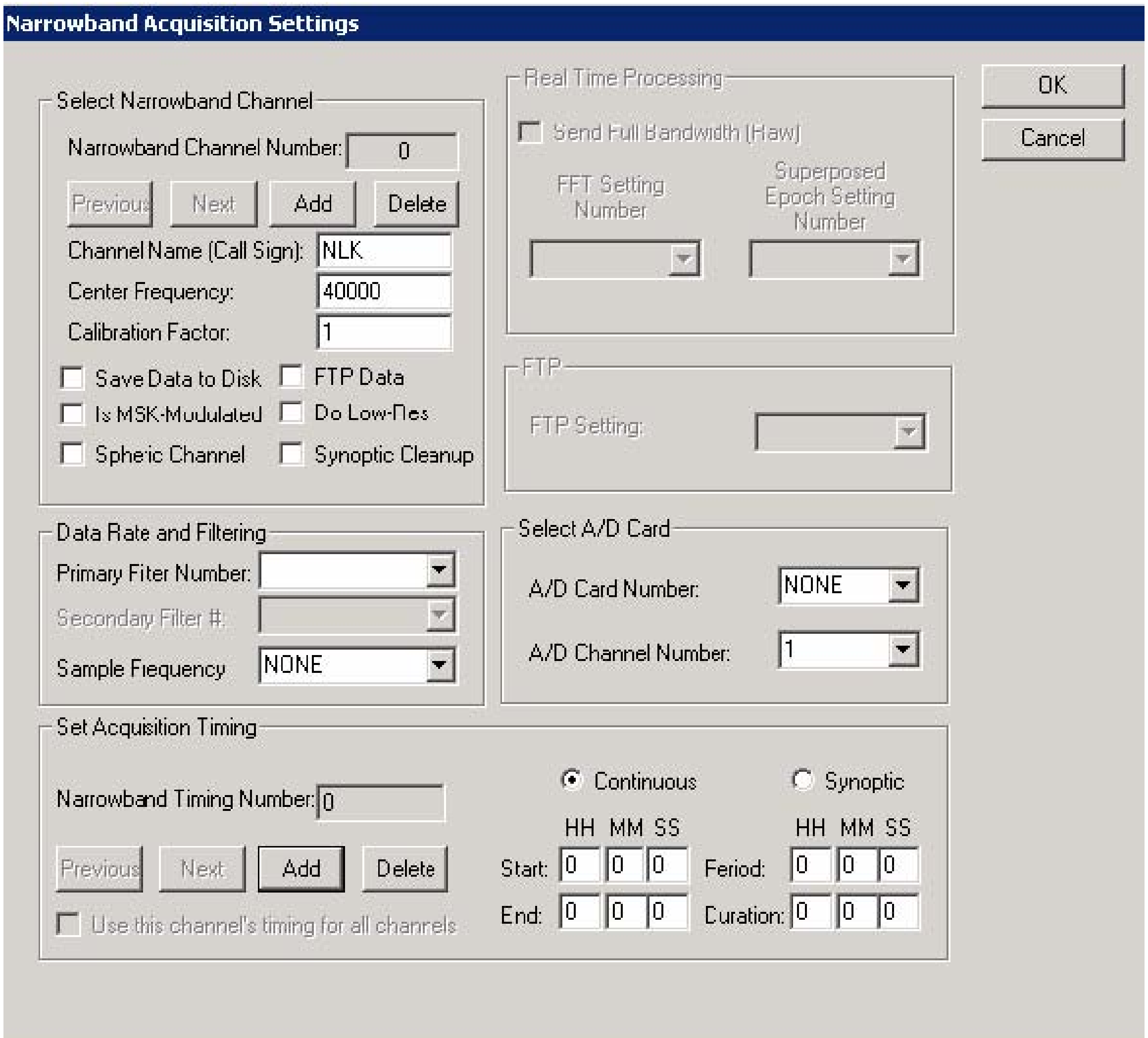
The software supports multiple channels of Narrowband data acquisition. To add a channel, simply click on the add button in the Select Narrowband Channel section. The save data to disk checkbox, if unchecked, will delete the data on the harddrive after it has been FTPed. The FTP data check box will FTP data using the specified FTP setting, which can be selected from the pull down menu. The synoptic clean up checkbox, if checked, will run the synopticCleanup.bat file after every synoptic acquisition. The Do Low-Res check box will create a matlab file containing 1 Hz data in addition to the regular settings of this channel. The spheric channel check box indicates if the channel is used for spheric detection. The MSK-modulated check box, if checked, will remove the phase modulation in the signal. For each channel, the user must specify which ADC card to acquire data from. Also, the user must specify which of the 2 channels (usually north/south or east/west) on the ADC card to acquire from. For each channel, the user can specify the Sample frequency that data will be acquired at. The 100kHz data will be decimated down to this frequency. For each channel, the user can specify a filter setting to be used from the filter settings created in the filter GUI.

For each channel, the user must specify the timing schedule for this channel. To add a timing schedule, simply click on "add" and enter the times.

Start time--The time that acquisition should start End time--The time that acquisition should end Period--For synoptic acquisitions, the period of acquisition. For continuous acquisitions, the length of data contained in each file. Duration--For synoptic acquisitions, the duration of each period. For continuous acquisitions, the length of data contained in each file.

For example, start time of 3:00, end time of 10:00, period of 1 hour, duration of 5 minutes will acquire data for the first 5 minutes of each hour from 3:00 to 10:00.

Note: The FTP pull down menu has been disabled since we do not allow multiple FTP settings un the current version.



Sample Walk Through of a Simple Acquisition

This tutorial will walk through the steps necessary for the following:

BROADBAND

. • Setup 2 continuous broadband channels acquiring from 3:30 to 3:00 (23.5 hours of the day).
. • We want the continuous broadband files to be split into 30 minutes segments.
. • The broadband data will be filtered with a cutoff of 12500Hz.
. • The broadband data will be sampled at 100kHz

NARROWBAND

. • Setup 2 synoptic narrowband channels acquiring data the first 5 minutes of each day starting at 0:00 and ending at 12:05.
. • The narrowband data will be filtered with a cutoff of 200Hz.
. • The narrowband data will be from the NLK transmitter, mixed down from 24800 Hz
. • The narrowband will be sampled at 50Hz
. • The narrowband data amplitude will be scaled by a calibration factor of 5.
. • We will run the synoptic cleanup batch file for the narrowband data
. • The narrowband data will be FTPed to vlf-europe.stanford.edu at 23:30.

1) Setup the necessary hardware

a) Install a 200kHz NIDAQ ADC card in the PCI slot of the computer.

b) Install the NIDAQ software, and properly assign the ADC card to be device number 1 using the NIDAQ software. Contact Eddie Kim for a copy of the NIDAQ software

c) Attach the line receiver to the ADC card.

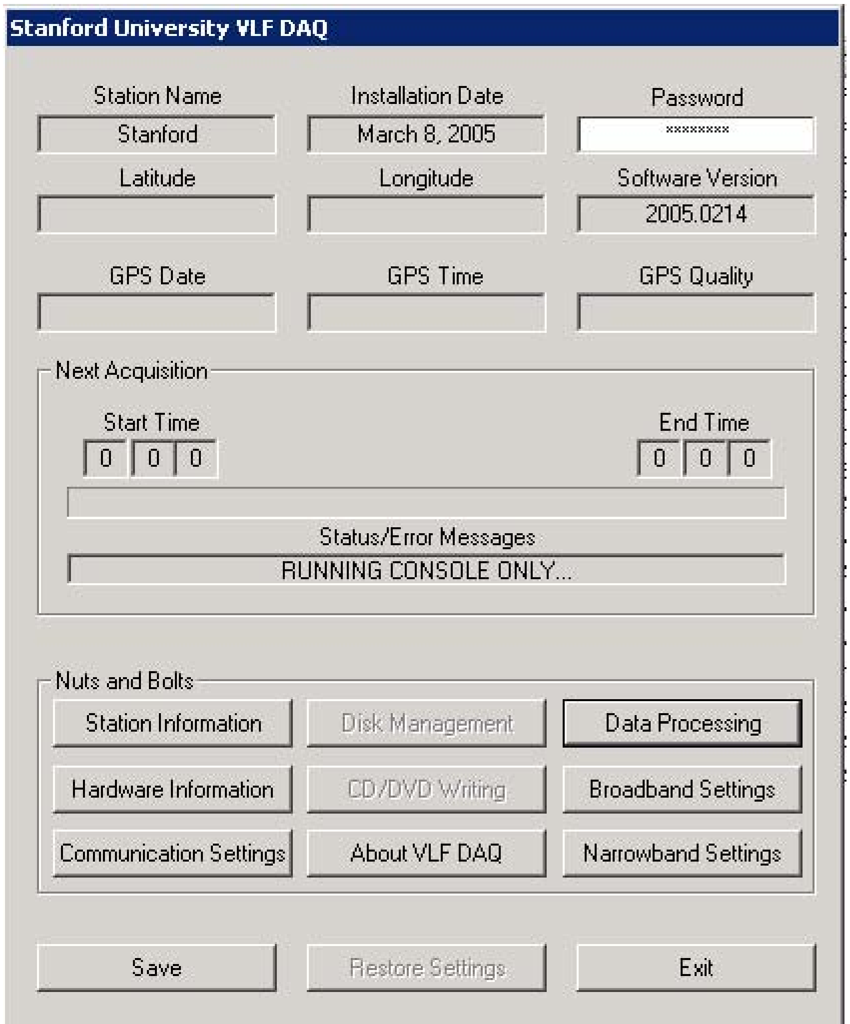
d) Attach the GPS receiver to the ADC card. Contact Morris Cohen for instructions on how to do steps c and d.

2) On the computer, install the software package

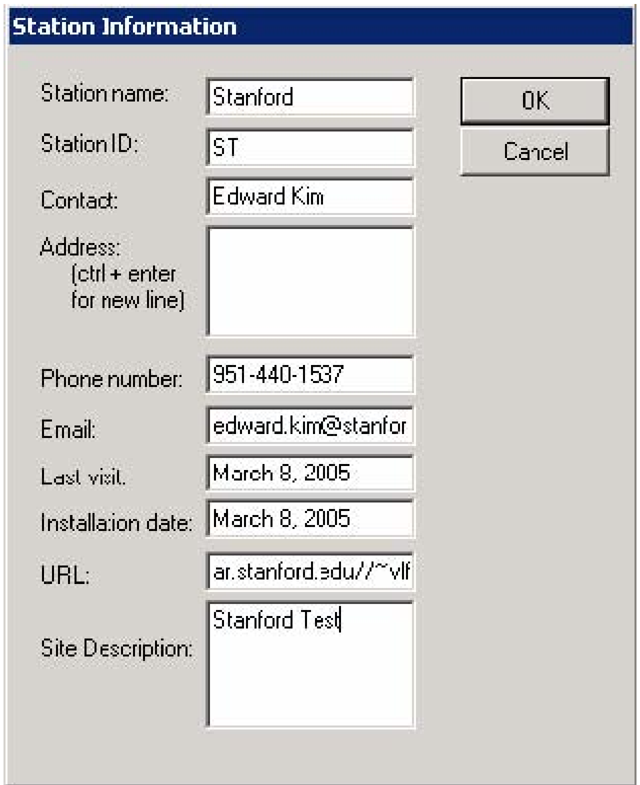
3) Make sure SPYSWEEPER and NORTON ANTIVIRUS scheduled scans are disabled.

4) Run the VLF_DAQ_console_only.exe. This allows the user to change settings or the software without fear of data being acquired while settings are being changed.

5) Enter the password in the password box.

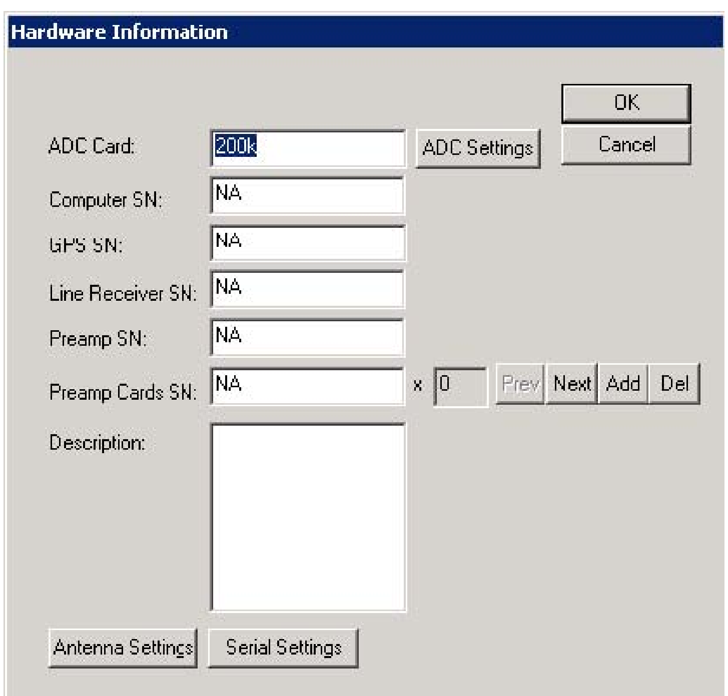


6) Click on "Station Information" and enter as much information as you can about the site. A copy of all this data is saved in the settings file, which is important to consult when studying your acquired data.

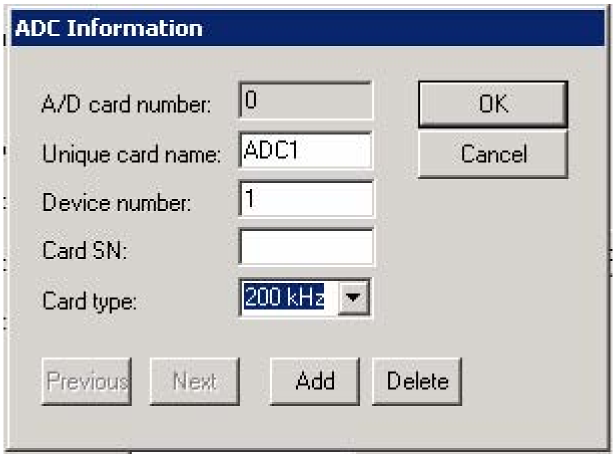


7) Click OK on the "Station Information" Dialogue Box

8) Click on "Hardware information" and enter as much information as you can about the hardware setup of the site.



a) Click on “ADC Settings”



b) Click “Add”

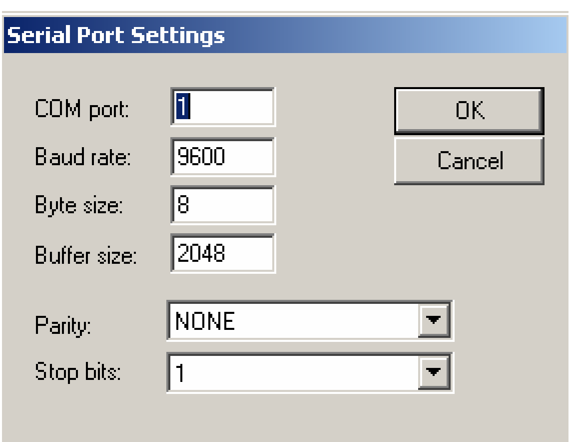
c) Type in “ADC1” for Unique Card Name

d) Type in “1” for Device Number

e) Under Card type select “200kHz”

f) Click OK

9) Click on Serial Settings.

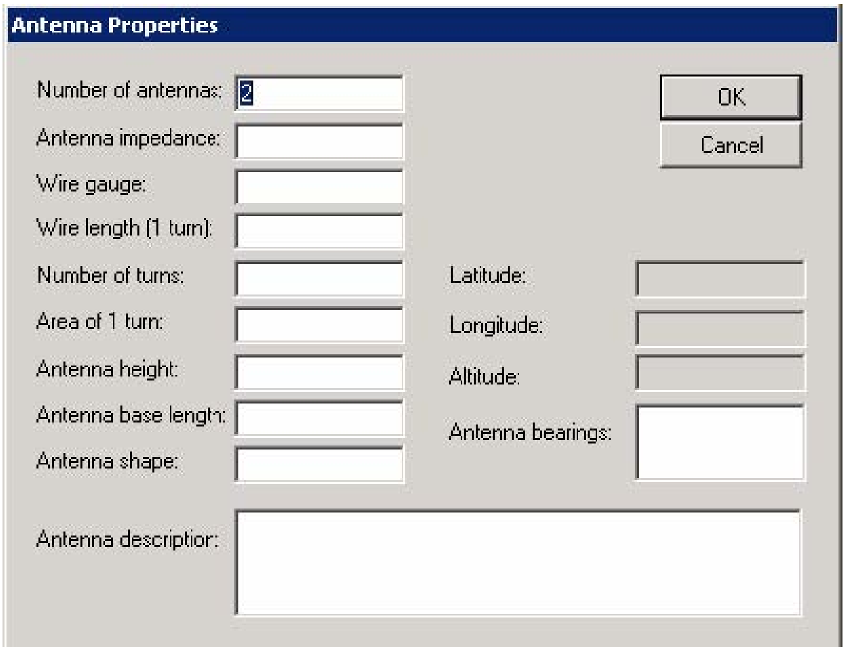


Motorola GPS system should use the following settings:
Baud rate: 9600
Byte size: 8
Buffer size: 2048

Parity: None
Stop bits: 1

Click OK.

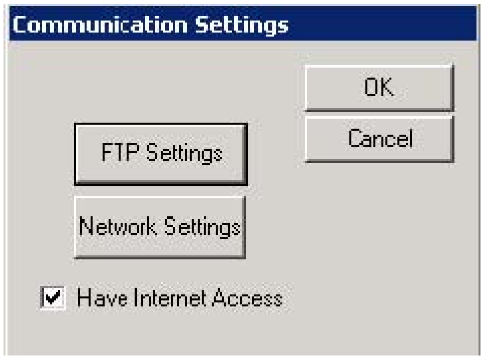
9) Click on “Antenna Settings” and enter as much information as you can about the antenna setup. A copy of all this data is saved in the settings file, which is important to consult when studying your acquired data.



10) Click OK on the Antenna Settings Dialogue Box

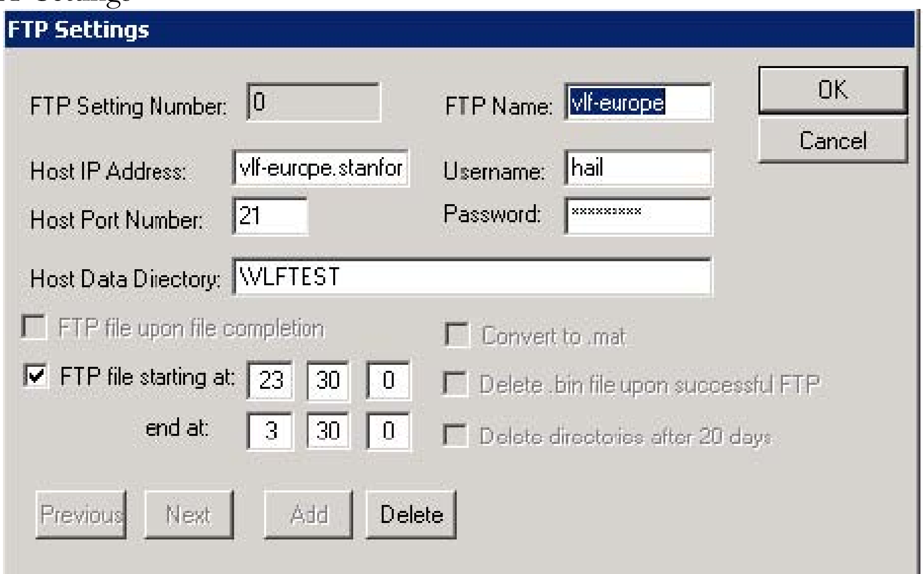
11) Click OK on the “Hardware information” dialogue box

12) Click Communication Settings



13) Check “Have Internet Access”

14) Click “FTP Settings”

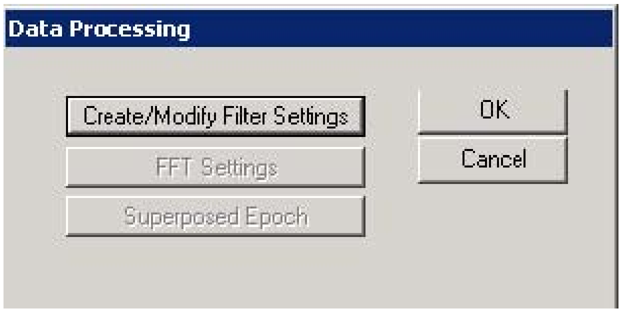


a) Enter “vlf-europe.stanford.edu” under Host IP Address b) Enter 21 under Host Port Number c) Enter the ftp username under username d) Enter the ftp password under password e) Check “FTP file” f) Enter 23/30/00 under “FTP file starting at:” g) Enter 3/30/00 under “end at:”. This will give 4 hours to FTP the files. h) Enter “vlf-europe” for FTP name i) Click OK

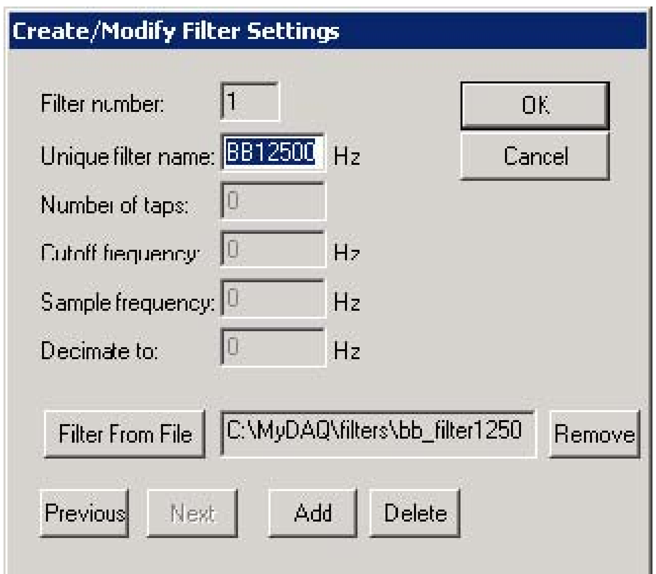
15) Click OK on the FTP Setting Dialogue

16) Click OK on the Communications Settings dialogue box

17) Click on “Data Processing”



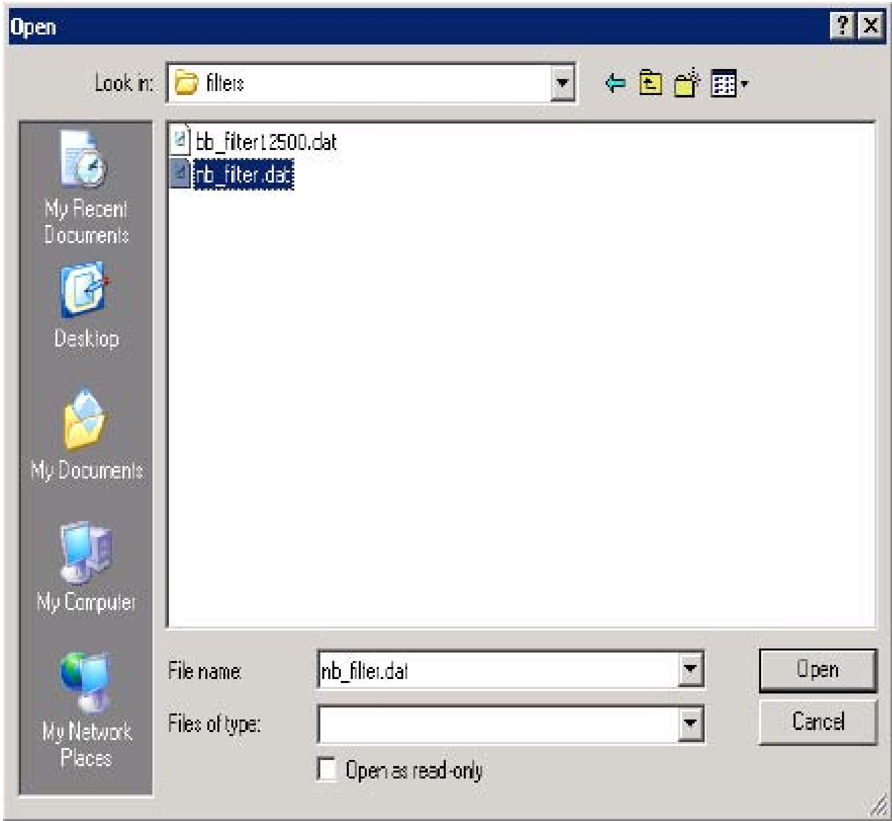
18) Click "Create/Modify Filter Settings"



a) Click "Add"

b) Enter "NB200" under Unique Filter Name

c) Click on "Filter from File"



d) Navigate to the Filter directory and select the file “nb_filter.dat”

e) Click OK to select the filter file

f) Click “Add”

g) Enter “BB12500” under Unique Filter Name

h) Click on “Filter from File”

i) Navigate to the Filter directory and select the file “bbfilter_1250.dat”

j) Click OK to select the filter file

k) Click OK on the “Create/Modify Filter Settings” GUI

19) Click OK on the Data Processing GUI

20) Click on the Broadband Settings button

a) Click on "Add" in the Select Broadband Channel section

b) Click "save data to hard drive"

c) Select 100kHz for sample frequency

d) Select BB12500 for primary filter

e) Select ADC1 for A/D card

f) Select 1 for A/D channel number

g) Click on "Add" in the "Set Acquisition Timing" section

h) Select Continuous radio button

i) Enter 03/30/00 for "Start"

j) Enter 03/00/00 for "End"

k) Enter 00/30/00 for "Period"

l) Enter 00/30/00 for "Duration"

m) Click on "Add" in the Select Broadband Channel section

n) Click "save data to hard drive"

o) Select 100kHz for sample frequency

p) Select BB12500 for primary filter

q) Select ADC1 for A/D card

r) Select 2 for A/D channel number

s) Click on “Add” in the “Set Acquisition Timing” section

t) Select Continuous radio button

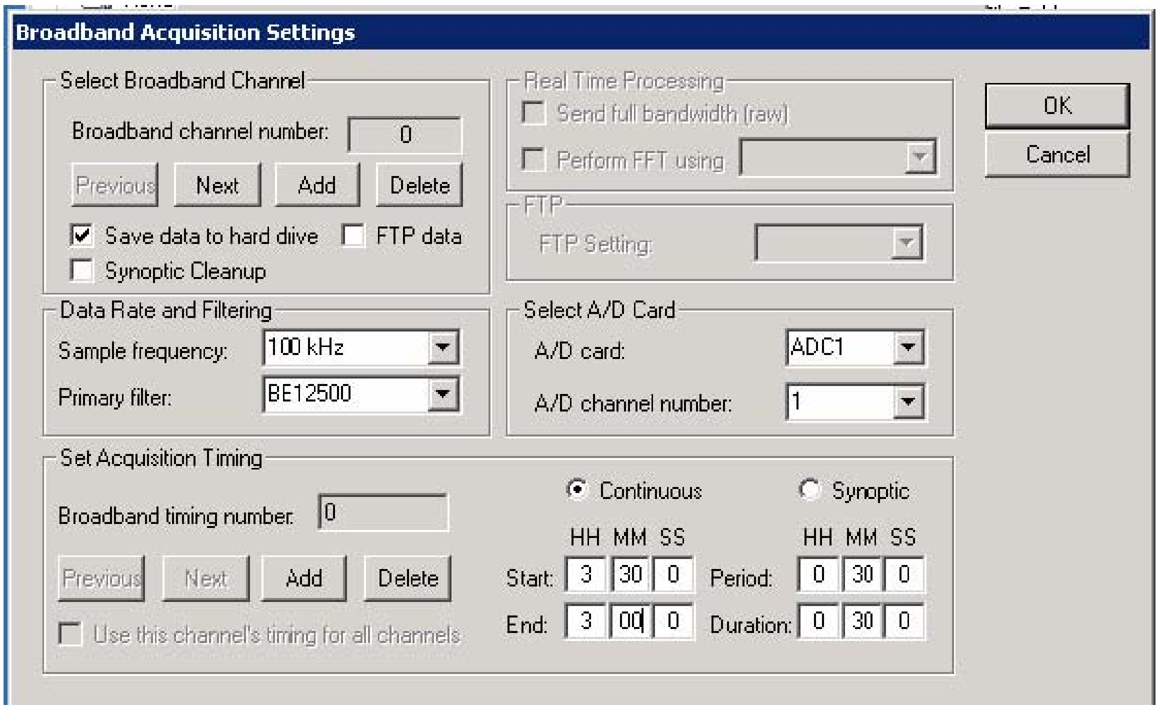
u) Enter 03/30/00 for “Start”

v) Enter 03/00/00 for “End”

w) Enter 00/30/00 for “Period”

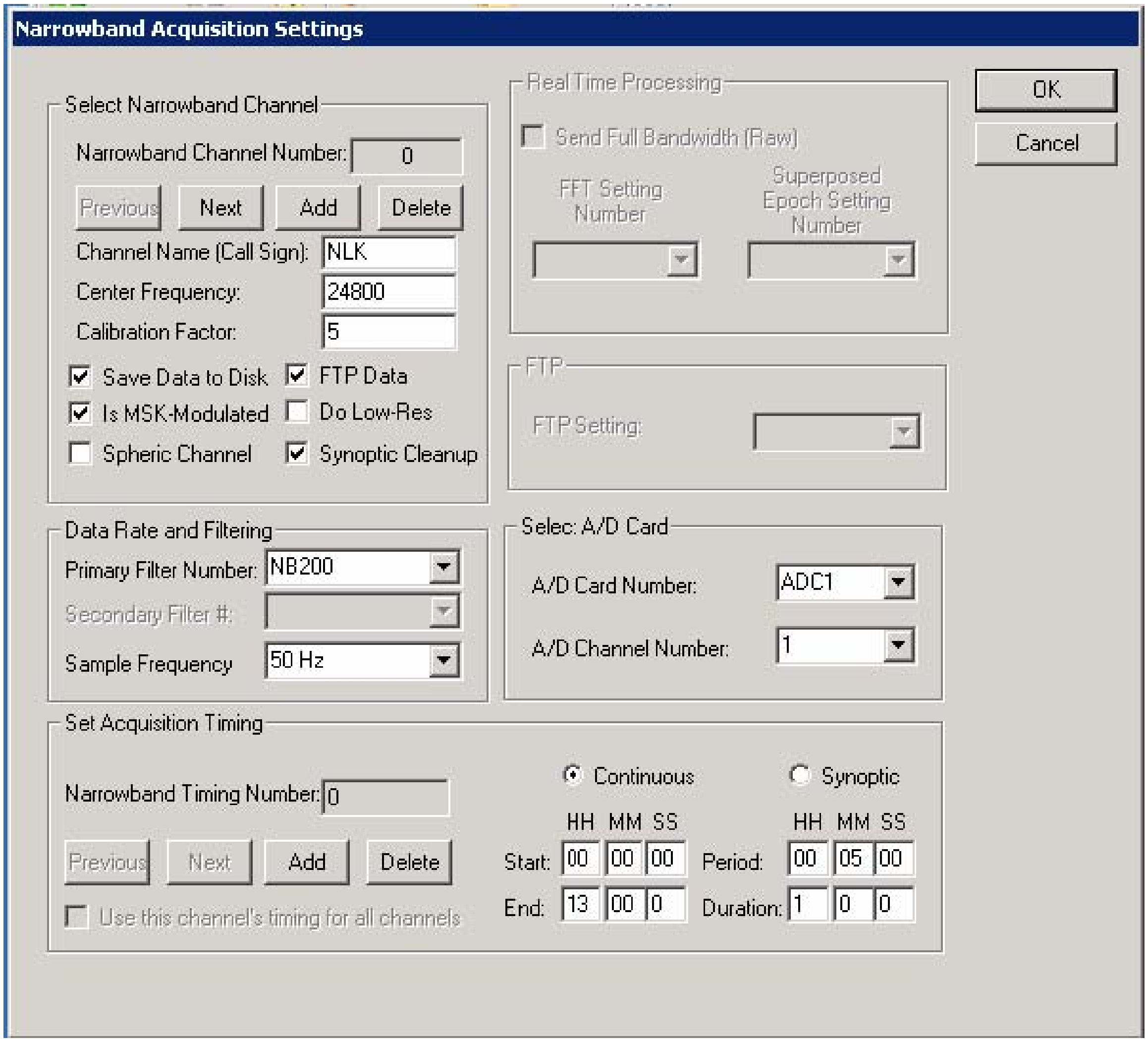
x) Enter 00/30/00 for “Duration”

y) Click OK



21) Click OK for Broadband Settings GUI

22) Click on the Narrowband Settings button



a) Click on "Add" in the Select Narrowband Channel section

b) Click "save data to hard drive"

c) Click "FTP data"

d) Click "Is MSK-Modulated"

e) Click "Synoptic Cleanup"

f) Enter "NLK" under Channel Name

g) Enter 24800 for Center Frequency

h) Enter 5 for Calibration Factor

i) Select 50Hz for sample frequency

j) Select NB200 for primary filter

k) Select ADC1 for A/D card

l) Select 1 for A/D channel number

m) Click on “Add” in the “Set Acquisition Timing” section

n) Select Synoptic radio button

o) Enter 00/00/00 for “Start”

p) Enter 13/00/00 for “End”

q) Enter 00/05/00 for “Duration”

r) Enter 01/00/00 for “Period”

s) Click on “Add” in the Select Narrowband Channel section

t) Click “save data to hard drive”

u) Click “FTP data”

v) Click “Synoptic Cleanup”

w) Enter NLK under Channel Name

x) Enter 24800 for Center Frequency

y) Enter 5 for Calibration Factor

z) Select 50Hz for sample frequency

aa) Select NB200 for primary filter

bb) Select ADC1 for A/D card

cc) Select 2 for A/D channel number

dd) Click on "Add" in the "Set Acquisition Timing" section

ee) Select Synoptic radio button

ff) Enter 00/00/00 for "Start"

gg) Enter 13/00/00 for "End"

hh) Enter 00/05/00 for "Duration"

ii) Enter 01/00/00 for "Period"

jj) Click OK

23) Click OK for Narrowband Settings GUI

24) Click "Save" on the main dialogue.

25) Click "Exit" on the main dialogue.

26) Restart the computer. The software should startup automatically at the start of the computer and the data acquisition will begin.

xviii. Deployment Checklist

The following items are needed or recommended for any deployment:

Preamplifier

Line Receiver

Belden 1217B Cabling (for preamp to line receiver)

Short Belden 1217B Cable (for initial testing)

Computer (set up with the following)

- DVD writer drive
- DVD burning software
- MATLAB
- DAQ Software
- National Instruments 6034E ADC Card PCI
- NI-DAQ Software (comes with 6034E)

Monitor, keyboard, mouse

Surge Protector/Powerstrip

Nullmodem Serial Cable

GPS Antenna

N-Type Cable (for connection to GPS Antenna)

Short N-Type Cable (for testing)

Portable oscilloscope

Portable function generator

Antenna post parts (specified for 4.39m base, 2.19m height, 6 turn isosceles triangle)

- Aluminum poles (3)
- ¼-20 bolts (6)
- ¼-20 nylok nuts (6)
- 5/16 eyebolts (2)
- 5/16 nuts (6)
- long guide wires with 5/16 eyebolts and turnbuckle (2)
- Carabiners (2)
- Terminal lugs to fit 6-32 screw/nut (4)

- Metal stakes (8)
- Plastic rollers (4)
- Plastic guards (4)

Antenna wire loops (2)

Toolkit, including pliars, wrench, hammer, screwdrivers, wire strippers, snips, spackle

Preamp mounting parts

Soldering iron and solder

Dummy loop

Cable connection for antenna to preamplifier (with 6-32 screwbolts and nuts)

1¼" PVC piping and hose clamps (for securing GPS antenna)

Compass (for aligning antenna)

Handheld GPS

Schematics and documentation

Sharpie (for labeling DVDs)

Blank DVDs

Spare filter cards, preamp cards, programmed FPGA, GPS card

BNC cables, banana plugs, alligator clips, wire

Multimeter

Power cables for computer, monitor, line receiver

Cable to connect line receiver to ADC card

Camera

Tape measure

Electrical tape

Caulk or other form of goop

Heavy duty putty

Drill

Bubble level (for aligning antenna)

Plumb (for aligning antenna)

Hum sniffer (for antenna spot selection and noise characterization)

Emergency help contact information: Morris Cohen (650-799-3674), Packard Room 12 (650-725-8446), Jeff Chang (650-814-0494), Packard Room 30 (650-723-1460), Umran Inan (650-804-0928), Ev Paschal (253-732-6910)

Maps

Cable ties

Spare fuses

Small machete (for clearing debris)

Walkie-talkie pair

Wood screws, nails

T-square

xix. Troubleshooting Guide

This guide will walk you through some of the common things that will go wrong should the receiver not function as it is supposed to. Diagnosing and fixing the problem may require the following: Oscilloscope, function generator, dummy loop, soldering iron, spare parts. For a given problem, follow each step in order, one by one, until the problem is solved.

PROBLEM: The blue light on the line receiver does not light up when it is switched on.
DIAGNOSIS: The +15V power supply to the motherboard is not functioning. This may be due to a failed power supply, a short in the circuit, or a loose connection.
SOLUTION:

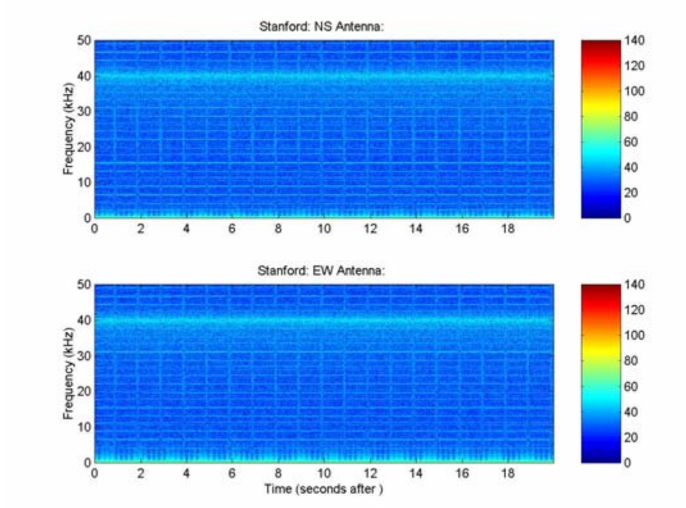
1. Make sure the power cord to the wall is plugged in correctly.
2. Turn off the line receiver, and unplug the four pin power connector that runs from the HAD15 power supply to the mother board. The end of the connector that plugs into the board has four pins on it. The single pin nearest the straight edge is ground. Next to it is an empty slot, followed by the -15V, and the +15V which is closest to the 45 degree angle side. Using a multimeter, check the voltage between +15V pin and the Gnd pin, and do the same for the -15V pin and the Gnd pin. If they are right, go to step 3. Check the voltage across the output of the HAD15 power supply. If they are correct, then the wiring from the power supply to the 4 pin connector may be loose or bad, so repair it.
3. There may be a short in the circuit. Using a multimeter, check the resistance between the +15V on the motherboard side of the power connector, and the ground, and then repeat for the resistance between -15V and the ground pin. If either is close to zero, there is a short somewhere on the circuit between those voltages. Please skip ahead for instructions how to repair that.

PROBLEM: When the software opens, the GPS time/location data is empty
SOLUTION:

1. Make sure the serial cable is firmly plugged in at both the line receiver and the preamp.
2.

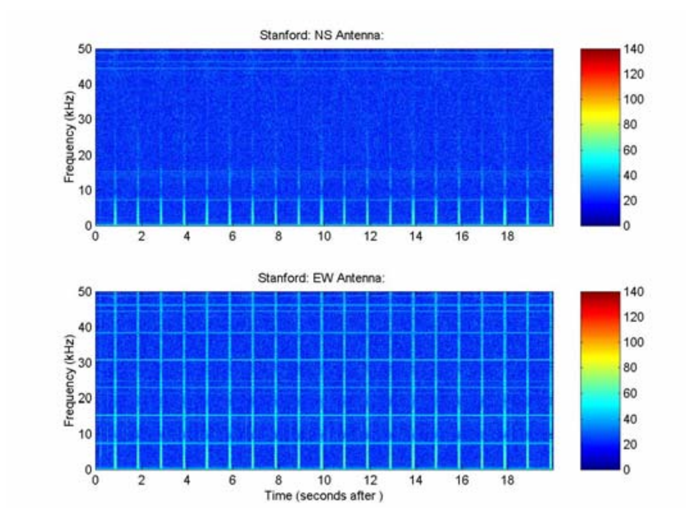
PROBLEM: The mouse is jumping all over the screen

DIAGNOSIS: The computer crashed and rebooted, and during its boot up process, Windows thought the GPS data on the serial port was a mouse.
SOLUTION: Turn off line receiver, reboot computer, and turn on the line receiver again only after the computer has finished rebooting.



PROBLEM: The data looks like this on both channels. (note, the light band at 40 kHz may not be there, but the key characteristic is the fact that it's mostly blue, and there are short vertical pulses once per second.)
DIAGNOSIS: The signal is getting cut off somewhere after the preamp card, but before the filter card in the line receiver.
SOLUTION:

1. Make sure the Belden cable is screwed in completely on both the preamp side and the line receiver side.
2. Make sure the "gain setting" light comes on inside the preamp. Note that you may have to turn the knob all the way around to see it. If it does not come on, you may have a bad Belden cable. Use a multimeter or function generator/scope to check that all 12 connections go through the cable (note that there are two unused pins on the connector), and that no signal is shorted to another one.

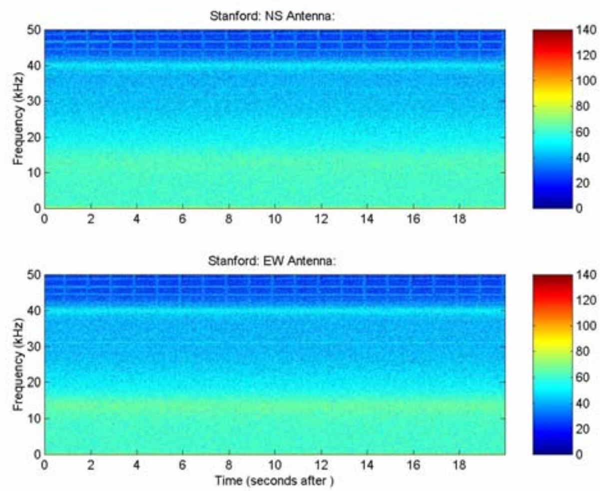


PROBLEM: The data looks like this on both channels (note that this is similar to the last one, except the 40-50kHz band shows no characteristic, here).
SOLUTION: The signal is getting cut off after the filter card. It is possible that the filter cards are not functioning, or have been removed. Try replacing them.

PROBLEM: The data looks like this on both channels.

DIAGNOSIS: The antenna signals are not reaching the input to the preamplifier.

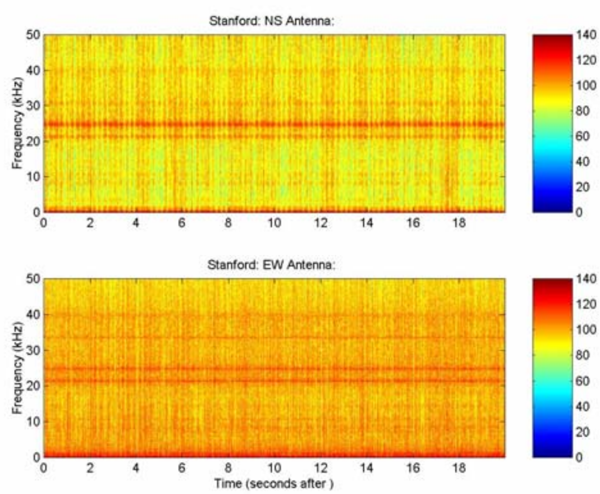
SOLUTION: Make sure the antenna connectors are firmly plugged in, that their signal runs smoothly to the preamp card. Try attaching a dummy loop to the input instead of the antenna, and inject signals using it. If you can see these signals at the output of the line receiver, then this either means the wiring from the antenna to the preamp is bad or incorrect, or that the antennae themselves may have broken, or gotten a discontinuity.



PROBLEM: The data looks like this on both channels.

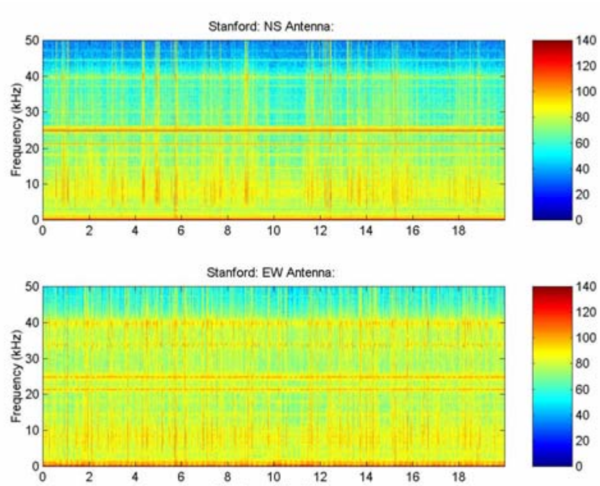
DIAGNOSIS: You have too much gain, so the receiver is clipping. This will likely be accompanied by the red lights above the BNC connectors on the front of the line receiver turning on.

SOLUTION: Turn down the gain in the preamplifier. 30dB should almost never be used, and 20dB only for particularly special cases. 10dB and 0dB are usually the best modes.



PROBLEM: The data has some bizarre horizontal stripes and dark/light pattern in it, looks like the EW channel in this spectrogram.

DIAGNOSIS: This is generally caused by 60Hz noise infecting the circuit.



SOLUTION: If the 30Hz boost jumper on the preamp card is out, put it back in. The 30Hz boost should be turned off at this site. If you are in 350Hz mode, you may want to consider turning on the 9kHz filter. This will give you much cleaner data but you will lose the frequency range below ~7kHz. Alternatively, move the antenna to a better location, further away from power lines.

xx. Additional Comments

The following additional notes should be known to those building or using an AWESOME receiver

1) There is an error on the preamp card, the ADG441BN (U8). Pin 13 should be connected to +15V, but it Is not connected on the circuit board. Thus it is necessary to manually solder a wire to some convenient +15V pin, like the positive side of C29. Note that without this fix, the system will still appear to work, but some distortion will be introduced due to this error.

2) T1 and T2 on both the line receiver's motherboard and the preamp's backplane are mislabeled. One of the sides is labeled "10 and Com" but this should really read "1W and Com". The Stancor A-8096 line transformer does not have a 10W pin.

3) VERY IMPORTANT SAFETY ISSUE: Make absolutely sure, when building a VLF receiver, that all pins that are attached to the 110VAC line are very well shielded and protected so that they cant be touched or shorted out. In the initial run of VLF receivers, the 60Hz EMI filter, power switch and fuse are placed behind a metal box, the same kind usually used in wall power switches. All exposed contacts are covered well with electrical tape or some other insulating material. The two contacts that connect to the external HAD power supply should be especially well covered and protected, since unlike the rest, they are not behind a metal box. IT IS HIGHLY RECOMMENDED THAT YOU AVOID TOUCHING ANYTHING WITHIN THE VLF RECEIVER WHILE THE POWER PLUG IS INSERTED.

4) The AuxB switch was accidentally shorted so one of the power lines, so it will not work. AuxA is not typically needed so this is not a major issue, but in order to use AuxB you will have to follow these instructions:

5) The polarities of the line transformers on the output of the preamplifier and the input of the line receiver are not properly labeled. Please use the following orientation when you are placing the line transformers:

6) A trace on the filter card must be cut, and the two ends connected with a 4.7uF ceramic capacitor. Please refer to the following diagram.

Justin Tan and Morris Cohen, the chief creators of the 2005 Stanford VLF receiver, would like to thank the following people for the help and contributions to this long but rewarding process:

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Joe Payne – For advice on the anti-aliasing filter card and GPS card

Use these pages for keeping your own comments about the Stanford 2005 VLF Receiver